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CORPUS CHRISTI STRUCTURAL BASIN POSTULATED FROM SALINITY DATA[1]

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ABSTRACT

Water wells completed in the Lissie and Beaumont show that artesian conditions exist in spite of supposed lenticularity. Analyses of 1,400 water samples yield a salinity map based on regional, smoothed-out lines of equal chlorine concentration (isosalinity lines) ranging from 500 to 4,000 parts per million.

Inability to correlate individual sands requires that the Lissie-Beaumont be treated as a single water sand. Sands, the water of which was sampled, lie beneath a shallow zone of highly saline ground water which is replaced under sandy soil by fresh water of surface origin. The strongest Lissie-Beaumont water analyzed had 9,578 parts, and immediately beneath the Lissie is water with more than 22,000 parts of chlorine.

After analogy with the Woodbine artesian sand of the East Texas basin, where isosalinity lines and structural contours are parallel, a wide swing of the lines around the head of Nueces-Corpus Christi Bay is considered to establish a Corpus Christi structural basin, provided the hypothesis of the down-dip flow of surface waters mixing with the original brines may be accepted as the explanation of the observed distribution of salinity in both regions. This hypothesis is favored.

Adjustment of the ancient, high-level delta of Nueces River of the Pleistocene to the postulated structural basin, and entrenchment in it of the present Nueces River with its drowned-valley bays, support the structural interpretation of the salinity map. Outside the "basin" the lines are parallel with the gulf shore line. The Beaumont outcrop in Nueces and San Patricio counties is the area covered by the survey.

Barton's top-of-salt contours for salt domes suggest that the other bays of Texas may lie in structural basins.

Theoretical stages in the evolution of mixed waters of coastal-plain aquifers (reservoir beds) are developed, several being found which could produce the observed salinity gradients of Corpus Christi and East Texas.

Opposing interpretations are briefly discussed. The probably varied nature of the connate waters of the Pleistocene may require a combination of methods to explain the observed salinity gradients with the numerous local chlorine "highs." One of the "highs" covers a producing gas field. Other "highs" are believed to be associated with diastrophic structure. Some are probably due to lenses of impervious sediments obstructing down-dip flow in the water sands. Their pattern does not seem to be that of

[1] A preliminary form of this paper was read before the Houston Geological Society, August 30, 1934. The present paper was read before the San Antonio Section of the Association, November 3, 1934. Manuscript received, December 22, 1934.

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shore-line features, such as lagoon and bay basins. The structural interpretation of the local chlorine "highs" is not studied in detail.

PROBLEMS OF ORIGIN AND SUBSEQUENT CHANGES OF UNDERGROUND WATERS OF STRATIFIED BEDS[3]

In studies of the chemical nature of underground waters in petroliferous provinces it has been noted that no waters of the precise composition of oceanic brines are now found, although they contain, chiefly, the common salts of oceanic waters. The range of concentration of these salts is both higher and lower than in ocean water. Some of these waters are found in strata containing marine fossils, and the assumption is commonly made that they originated as oceanic brine. In such cases it is evident that many changes have occurred in the brines since they were deposited with the enclosing sediments.

Changes which have occurred in original (connate) oceanic brines now found in the strata may be ascribed to several processes, such as the addition of minerals dissolved from the sediments of the reservoir; reactions between the dissolved minerals; the mixing of the connate water with invading solutions entering through fissures or through capillary openings in the enclosing beds; the invasion of the reservoir by, or movement within it of, petroleum and natural gas and the subsequent reactions, such as the evaporation of water into bodies of gas, the possible reduction of sulphates by petroleum or by anaerobic bacteria present in petroleum; and the possible expulsion of water from the reservoir accompanying the compaction of the strata with base exchange reactions occurring in the roof clays. Some changes may have accompanied variations in temperature and pressure of the waters as the overlying column of sediments was increased by deposition or decreased by erosion.

Since water-bearing beds include both fossiliferous and non-fossiliferous strata, it is a matter of speculation whether the water contained in them at the time of their deposition was of fluviatile, lacustrine, lagoonal, marine, or soil origin. The problem of supposedly dry, or only slightly saturated, strata has received some consideration.

Another group of problems is concerned with the movements of underground waters. Much discussion has centered around the possible accumulation of oil and gas through the movements of underground waters. The artificially induced water-drive has been carefully studied in the Bradford field of Pennsylvania. The rise of deep-

[3] For a recent statement of the principal problems, see Washburne and Lahee (1934). Dates in parentheses following authors' names, and names and dates in parentheses, refer to References at the end of this article.

seated saline solutions around salt domes has received some attention. Penetration of surface waters into reservoir strata, including both fresh water from the ground surface and brine from oceanic basins, is an important problem. In the matter of the entry of surface waters into outcropping strata or buried strata lying at shallow depth, the question of variations in the entering ground waters produced under varying climates is to be considered.

In the mixing of underground waters of different types, what is the rôle of diffusion? To what extent may diffusion cause the migration of radicals of dissolved minerals, and to what extent may our hypotheses thereby be freed from the necessity of postulating the actual flow of the waters underground under natural conditions? If a water-bearing stratum saturated with brine has appreciable dip, may there eventually occur a gravitative settling of the dissolved mineral salts so that a gradient of increasing salinity may be produced in the direction of the deeper parts of the bed? If so, what is the time element involved and how flat a dip will produce such a down-dip concentration?

Although most of these problems are of a theoretical nature and not many data can be brought directly to bear on them, as many as seem pertinent to the present problem and within the scope of the investigation are briefly discussed.

The chemical analyses made for the present study did not include determinations of all the ions present. The data, therefore, do not warrant an inquiry into the past changes in the composition of the brines, excepting as to the single radical, chlorine, whose variations are studied. Complete water analyses are needed for a comprehensive study of the evolution of ground waters. The Palmer method (Palmer, 1911; Rogers, 1917; Rogers, 1919, pp. 52-56) of classification of waters into those showing primary or secondary salinity or alkalinity is the most useful so far devised in the study of the evolution of ground waters.

Although the obscurity of the origin of some ground waters and the difficulties in attempting to outline the changes which have occurred in them are recognized, it is pertinent, in the light of the close correlation between variations in salinity and structure in East Texas to ask whether, on the basis of the salinity data alone, some of the problems of the origin and evolution of ground waters of artesian type may not be studied with a reasonable hope of success.

The most pertinent question of the present study has been well phrased by Washburne and Lahee (1934, p. 833).

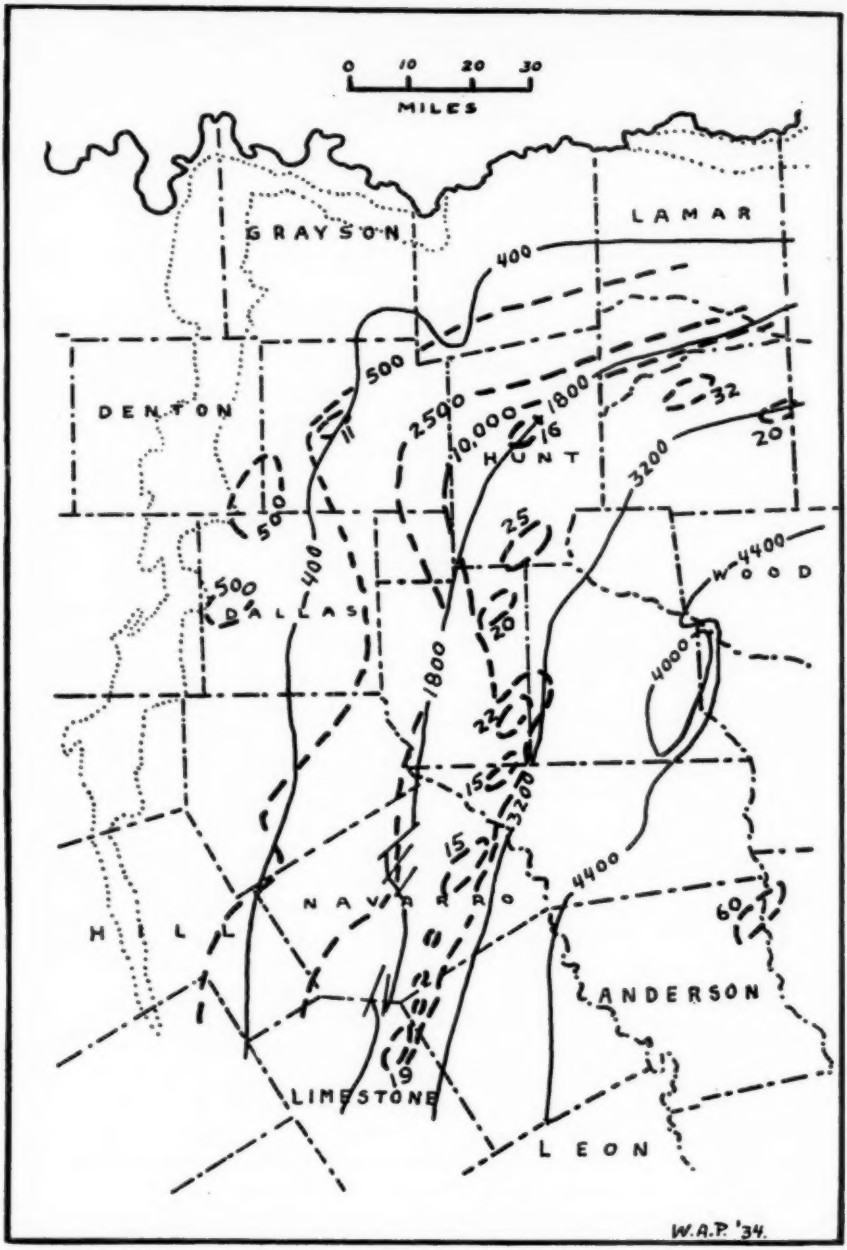

FIG. 1.—Parallelism of isosalinity lines and structural contours for Woodbine of East Texas, after Plummer and Sargent (1931, Pls. I and VIII). Dotted line, Woodbine outcrop; full lines, structural contours; broken lines, isosalinity lines with figures in parts per million by weight for chlorine. Figures on isosalinity closures are chlorine values for closing line in parts per thousand. Detailed structure of fault-line fields not shown.

Are the present local characteristics of deep waters related to topographic or physiographic conditions of the time when the containing sediments were laid down, or are they related to structural features developed much later? Can they be used as indices of structural conditions . . . ?[4]

REGIONAL SALINITY IN ARTESIAN BASINS

In the East Texas structural basin, the Woodbine sand is an ideal example of an artesian reservoir—a permeable sandstone which extends from the outcrop to depths of more than 4,500 feet below sea-level and which is saturated with water. The Woodbine water shows a gradual increase in salinity from very fresh water near the outcrop to waters at least as highly concentrated as sea water in the deeper parts of the basin. On piercement salt domes in these deeper areas are waters much more concentrated than sea water.

This range in salinity has been held by geologists to be due to the dilution of the original oceanic waters by surface waters entering at the outcrop and flowing slowly and steadily down the dip of the formation. Brine from rock salt of pre-Tertiary age has contaminated small areas of Woodbine sand around the interior group of salt domes.

Plummer and Sargent (1931) have shown that the salinity of the Woodbine waters increases at a relatively equal rate down the dip of the formation from all points along the outcrop. The result of this condition is that the isosalinity lines closely parallel the structural contours drawn on the top of the Woodbine (Fig. 1). This statement applies especially to regional salinity and regional structure, but local chlorine anomalies in East Texas in the Mexia-Powell line of faulted anticlines and on the salt domes closely coincide with the local structural elevations.

Whether the East Texas salinity gradients are typical of water-bearing formations in basins of artesian type is a problem which rightfully invites attention, for, if they are typical, then salinity gradients may be used as a means of determining regional structure where artesian conditions exist. No geologist seems specifically to have taken the position with regard to this artesian basin that the gradients of salinity were produced in any other manner than that described by Plummer and Sargent.

The chlorine radical was chosen as an indicator of structural conditions in the aquifers and, by implication, in the underlying oil and gas sands, because of the known relationship of salinity and structure in the Woodbine of the Mexia-Powell district, and because of the rel-

[4] The words omitted in the quotation are: "favorable to oil accumulation." The writer takes the liberty of using the quotation with reference to regional structure.

atively great difference in expense between making analyses of the chlorine content and making full chemical analyses of water samples. Determinations of the sulphates and carbonates were added in the hope that these radicals might contribute to the location of oil-bearing structures, but the results from the study of the occurrence of these radicals have been negative, in that they seem to show a wholly irregular distribution.

The problem of this paper is to determine whether the observed distribution of chlorine concentration in the Pleistocene water sands of the Corpus Christi area (Fig. 2) indicates the presence there of an artesian basin similar to that of East Texas. If it does, the area for which the writer has chlorine analyses in the Corpus Christi district represents the zone of very dilute waters nearest the outcrop, that is, the zone of potable waters.

The highest observed chlorine concentrations in the Corpus Christi area are 6,207 and 9,578 parts per million. They represent isolated wells. The highest isosalinity line which may be drawn is the line of 4,000 parts. In East Texas, the water samples were obtained from wells drilled for oil and analyses are available for drawing the isosalinity lines almost to the 19,000-parts line, which represents the updip boundary of the area of oceanic waters not yet invaded by waters which have entered the outcrop from the surface.

A further limitation of the present study is the lack of data for the correlation of individual water sands and lenses and the consequent necessity of treating the strata of the Pleistocene formations—Beaumont and Lissie—as a single unit. Although the two formations together are perhaps as much as 1,200 feet thick, most of the water samples were obtained from depths between 240 and 800 feet and probably represent chiefly the lower Beaumont and several porous sand beds of the Lissie.

The regional structure of the Corpus Christi area is known merely as a gulfward-dipping homocline, there being, at present, in the writer's judgment, insufficient data to determine the details of the regional structure. The available data (Fig. 6) do not seem to be in conflict with the postulate of a structural basin coinciding, in general, with that suggested by the isosalinity lines here described. It is known, however, that some geologists believe that Nueces River flows through or along a regional up-warp. The writer has not seen conclusive data on this supposed regional anticline.

DEFINITIONS IN GROUND-WATER TERMINOLOGY

Before an interpretation of the distribution of salinity in this area is attempted, it will be well to define a few essential terms, not al-

ways uniformly used by writers. Most of these are derived from Meinzer (1923a), but not all have been found in a single publication.[5]

Atmospheric waters, or *meteoric waters*, include all water in the atmosphere. The term "meteoric water" is sometimes used for waters in the earth of recent surface origin.

Surface waters occur on the surface of the earth, as in rivers, lakes, oceans, and bays.

Subsurface waters include all waters beneath the earth's surface.

The *zone of aëration* is a relatively shallow zone in the soil, or in fissures or interstices beneath the soil. It is filled chiefly with atmospheric gases, but contains some water held by molecular forces—capillarity—in the smaller interstices. The molecular forces prevent this water from being drawn down by gravity to the zone of saturation. It is not under hydrostatic pressure. This water may be great in amount. It has been called *vadose water*.

Upper zone of saturation.—The permeable rocks which lie below the zone of aëration are generally saturated with water under hydrostatic pressure. It has been drawn down by gravity through the zone of aëration. The part of this water which will drain into wells is called *gravity ground water*. Part of the water of this zone will be retained as films around sand grains, and part will remain in capillary interstices. There may be several *lower zones of saturation* separated from the *upper zone* of saturation by impervious strata.

Ground water is that contained in the zone of saturation, including both the gravity ground water and water which will not flow out of the strata. The older term "phreatic water" is a synonym for ground water.

The water table is the upper surface of free ground water where it is naturally unconfined above by impervious material (see "piezometric surface"). In arid regions it may be as much as 100 feet below ground surface.

A piezometric surface of an aquifer is "an imaginary surface that everywhere coincides with the static level of the water in the aquifer. It is the surface to which the water from a given aquifer will rise under full head" (Meinzer 1923b, p. 38). A piezometric surface is to be sharply distinguished from the water table.

Impermeable rocks are those whose permeability is too low to permit water to pass through them under the existing hydrostatic or

[5] After this paper had gone to the editors, the writer's attention was called to Meinzer's "Outline of Ground-Water Hydrology, with Definitions," U. S. Geol. Survey Water-Supply Paper 494 (1923b), where these definitions are more fully elaborated in some cases.

hydraulic pressures. It is a relative term. A bed which is impermeable or relatively impermeable under present conditions may have been permeable, or more permeable, under previously existing conditions. A bed which is impermeable to hydrostatic or hydraulic forces may, however, be permeable to water moving under molecular forces. Impermeable rocks may contain water held by capillary forces, but yield no gravity ground water.

An *aquifer* is defined by Meinzer (1932).

> A rock formation or stratum that will yield water in sufficient quantity to be of consequence as a source of supply is called an "aquifer" or simply a "water-bearing formation."

Artesian aquifers are those which contain water under sufficient pressure to cause it to rise above the top of the aquifer toward the surface in a well or other outlet. The upper end of the aquifer bed may extend into the zone of aëration and not yield gravity water to wells, but be continuous with the water-yielding part. Requisite conditions for artesian flow are (1) adequate source of water, (2) a retaining agent (*cap*) offering more resistance to the passage of water than the well or other opening, and (3) an adequate source of pressure. This pressure is, in most cases, wholly hydrostatic. The flow in the aquifer is too slow to develop appreciable hydraulic (kinetic) pressure.

Flowing wells are those in which the water rises under its own pressure from an artesian reservoir to the surface of the earth, where it will flow from the well mouth.

Non-flowing wells may draw water from (1) an artesian aquifer which has insufficient pressure to raise the water to the ground surface, or from (2) a non-artesian aquifer.

Non-artesian aquifers lack an adequate cap or adequate pressure for artesian flow, or their water content has been depleted. Variations in permeability in a stratum may prevent its having artesian pressure, in effect dividing it into separate, non-communicating aquifers, thereby reducing the hydrostatic head for any part tapped by a well. Depletion of an aquifer may occur through erosion, or through use of the water, or, in part, by lowering of the head by evaporation at the outcrop.

An *isosalinity line* is a line drawn on a map through points of equal value for a given indicator of salinity. Chlorine concentration, concentration of total solids, or the specific gravity of the water may serve as salinity indicators.

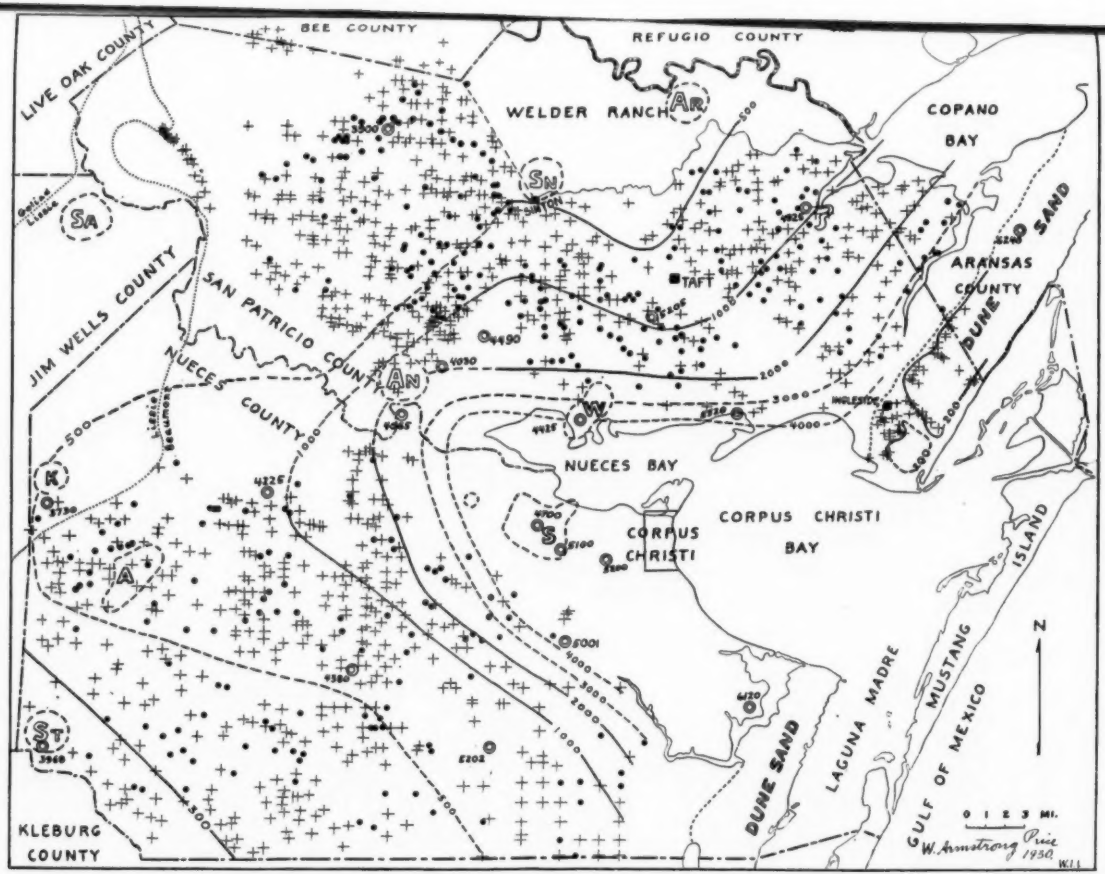

FIG. 2.—Regional isosalinity lines for Pleistocene water sands of Corpus Christi area; contours, based on parts per million of chlorine by weight in water samples. Dots and crosses show water wells sampled (Price, 1932, Fig. 1). Oil and gas fields outlined by broken lines (these lines have no significance other than to designate approximate positions of fields—they are not salinity lines): *A*, Agua Dulce; *An*, Angelita; *Ar*, Aransas; *K*, King; *S*, Saxet; *Sa*, Sandia; *Sn*, Sinton; *St*, Stratton; *W*, White Point. Lissie-Beaumont contact follows Plummer (1932, p. 754, Fig. 50). Figures for deep wells drilled for oil and gas (double circles) show depths below sea-level to top of *Heterostegina* zone, some being determined by interval or correlation for wells where fossils were not found or not reached.

WATER-WELL SURVEY

The chlorine content of water from Pleistocene sands was determined in a survey of well waters of the Beaumont and Lissie formations in Nueces and San Patricio counties, Texas, made in 1930. About 1,400 water wells (Fig. 2) ranging in depth from 30 to 1,200 feet were sampled. Other radicals determined were SO_4 and HCO_3.[6]

The wells sampled were cased with pipe. A few wells were pumped from the cisterns of dug wells. These showed very fresh waters. Excepting wells supplying towns, all the wells are pumped by windmills.

All of the wells, excepting a small minority sampled from tanks, were sampled from a flow pipe direct from the casing. Since most tank samples showed locally low concentrations, it is supposed that rain water had contaminated them. A few tank samples showing sharp local differences in salinity were disregarded.

No attempt was made to pump off the head of water in the casing before sampling or to test for casing leaks. Because of the presence of a shallow zone of highly saline water, most casing leaks should show as isolated cases of locally high salinity.

No written logs or other written records of the wells were available, excepting for a very few wells. Some large ranches in the two counties have files of well logs, but these ranches were not included in the survey. An examination of a set of water-well logs for one ranch failed to show data for correlating sands. Total depths of the wells sampled were recorded when the driller or owner seemed to have a reasonably clear recollection of the figures.

DISTRIBUTION OF WATER WELLS SAMPLED

Blank areas, showing no wells on the map (Fig. 2), include western areas where the water sands of the Pleistocene were believed to crop out or to be very near the surface; areas of large ranches not entered; where rain water or river water, or water piped from towns is used instead of well water in areas where the chlorine concentrations were greater than 1,000 parts per million, and especially where they were greater than 2,000 parts and 3,000 parts, and areas on dune-sand ridges which border the coastal lagoon where shallow fresh waters are obtained. Some of these shallow dune-sand waters were sampled in the Aransas Pass and Ingleside areas.[7]

[6] Minute globules of oil found disseminated in the water were discussed in an article describing some of the results of this survey (Price, 1932). Acknowledgments to associates in this survey were made in the prior article. Some conclusions of the present paper supplant some of the incidental statements of the former article.

[7] These dune-sand ridges have been described as segments of a formerly more or less continuous offshore bar (Fig. 3) which retreated to shore in late Pleistocene time. This former bar has been called the Live Oak mature offshore bar (Price, 1933b).

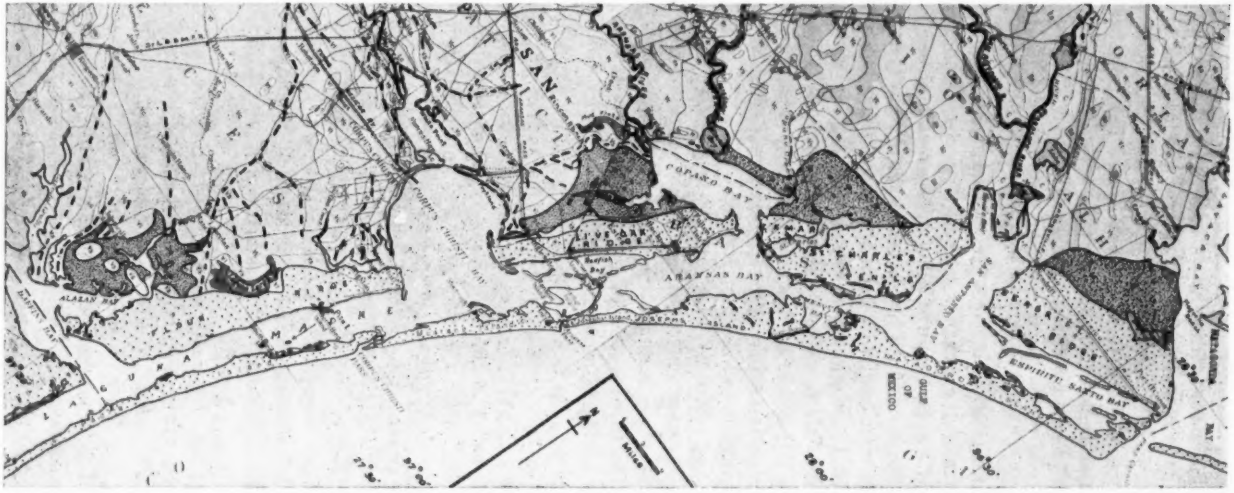

FIG. 3.—Delta of ancient Atascosa-Nueces River shown on part of reconnaissance soil map of South Texas. Present Nueces River enters head of Nueces Bay. Broken heavy lines radiating from points near present river indicate remnants of distributary ridges of ancient delta. Front of exposed part of delta is cut by Ingleside Terrace scarp. Deposits of this terrace (heavy, dotted stipple) and dune sand of Live Oak mature offshore bar (light dotted stipple west of coastal lagoon) with waters of Corpus Christi Bay overlie lower parts of deltaic deposits. Northeast extremity of delta was at Copano Bay and southeast extremity at Baffin Bay. (This figure appeared as Figure 3 of Price, 1933b, to which the reader is referred for further physiographic descriptions.)

Where the chlorine content in the water is as high as 4,000 parts, almost all farms have abandoned such wells as were drilled.

Areas between Calellen and Corpus Christi and back some miles from the river receive water from Nueces River. The area between Taft, Gregory, and Ingleside is served with water piped from the Central Power and Light Company's wells at Taft.

FRESH WATER UNDER LIVE OAK MATURE OFFSHORE BAR

Mustang Island (Fig. 2) is one of several islands and peninsulas of sand which parallel the Texas coast and form the offshore bar of the present period. In the Corpus Christi area a mainland sand ridge fronts the coastal lagoon which lies between the present (young) offshore bar and the mainland. The mainland ridge is divided by bays into five segments. These segments are shown in Figure 2 as areas of dune sand. North of Corpus Christi Bay, the coastal ridge is called Live Oak Ridge. The towns of Aransas Pass and Rockport are on this ridge. Ingleside is at its southwest margin. South of Corpus Christi Bay the ridge is called Flour Ridge.

These ridges are 3–8 miles wide and rise 20–30 feet above sea. They stand on Beaumont clay at 8 feet above sea, where they are best exposed. Fresh-water springs issue at the base of the sand. These two ridges and the three others in the same alignment along the coast on the north (Fig. 3) have been described (Price, 1933b, pp. 918–21, 929, Figs. 2, 3, 4, 6, 8) as a mature offshore bar which retreated to shore in late Pleistocene time. This ancient bar (Fig. 3) has been called the Live Oak mature offshore bar (Price, 1933b).

Fresh, potable water, with chlorine ranging from 90 to 240 parts per million, is found in sand lenses of the Beaumont to 100 feet below surface on this bar. The water stands 30–40 feet below surface in wells. Similar penetration of the Beaumont by fresh water was noted in other localities beneath sandy soils formed by ancient distributary ridges (Fig. 3) of Nueces River (Price, 1933b).

Identical shallow reservoirs of fresh water exist beneath the offshore bar of the Netherlands. Seaside populations, including the city of Amsterdam, find this water a chief source of supply (Brown, 1925; Versluys, 1931).

Penetration of the clay overlying and separating the sand layers beneath offshore bars, with displacement of the brine, has been shown to be due to the slight head of fresh water accumulated in the sand ridge after rains. The depth of penetration of the fresh water beneath the surface is said to be proportional to the height of the hydrostatic head of fresh water and the difference in density between the fresh

and salt waters, according to the law of Herzberg (Brown, 1925, pp. 16, 17). To apply the law the subsurface conditions would have to be accurately known. Equilibrium is attained when the downward pressure of the fresh water balances the counter pressure of the brine. Since the movement of water through the capillary openings in the clay must be slow, a factor of time enters before equilibrium is attained. This time is, presumably, too short to be regarded from the geologic standpoint.

That this type of near-surface fresh-water reservoir may be formed only in humid areas, that is, during periods of humidity, is suggested by its apparent absence under the extensive sands of the South Texas "Desert" (semi-desert) of Kenedy and adjacent counties (Price, 1933b, pp. 928-29, Event 2c, Figs. 2, 6A. The fresh, near-surface ground water reported on page 945 is not at Sal Vieja and Sal del Rey, but south of Lyford, and originates from irrigation and Rio Grande floods). This "desert" now has a semi-arid climate and apparently has had this climate since its formation in late Pleistocene time.

ANALYSES AT INGLESIDE, SAN PATRICIO COUNTY

Sufficient analyses to show the character of the vertical chlorine gradients in the area are available only at a single locality, from a radius of 1 mile around the town of Ingleside, at the edge of the Live Oak mature offshore bar.

TABLE I

WATER ZONES AT INGLESIDE, SAN PATRICIO COUNTY, TEXAS

Depth to Top of Sand in Feet	*Chlorine in Parts per Million*	*Description*
		Near-surface reservoir of potable water, infiltration into Beaumont
?	90	One sand, well 123, Price Survey
58	220	One sand, well 140, Price Survey
		Near-surface saline ground water of Beaumont, somewhat diluted (?), with inter-lensing of fresher waters from above
76	2,335	One sand, well 137, Price Survey
90–164	338*	From one of three adjacent wells; sample probably from more than one sand
92– 94	800–1,020*	Limiting values from this sand in a group of adjacent wells at oil refinery
92–127	1,130*	Mixed sample from 3 sands in one well
149	920*	One sand in well at oil refinery
		A normal Beaumont-Lissie water for this locality according to regional isosalinity lines of Figure 1
259	4,620*	One sand in well at refinery
		Includes some water from below Lissie (?), from Goliad (?)
502–1,720	21,750*	Mixed sample from 7 sands in one well at refinery

* Analysis from Baytown Refinery, courtesy of Humble Oil and Refining Company.

The value of this series of analyses in showing a typical vertical gradient is lessened by the dilution of Beaumont waters by fresh water from the bar and by the mixed nature of some of the samples of water. It is not known that the lower sands in the deepest well listed in the following table are Lissie. They may lie below the Lissie. The water of the mixed sample taken between 502 and 1,750 feet in this well shows a chlorine concentration in excess of that of ocean water and 4.5 times as strong as the water from 259 feet in an adjacent well.

WATER-BEARING ZONES OF BEAUMONT-LISSIE

Water-well drillers report the general occurrence of near-surface saline ground water extending from the surface to a depth of 80 feet, and possibly, in some places, to 200 feet or more. This upper saline ground water is too salty for use and is cased off in the wells. It seems to be everywhere present in the area, although locally diluted or replaced by fresh waters which have descended into the Beaumont under sandy soils, as in the case of the upper 150 feet beneath the Live Oak mature offshore bar at Ingleside (Fig. 3).

This zone of upper saline ground waters is imperfectly known as to depth and analysis, because of lack of wells completed in it. The zone shows a maximum chlorine concentration of 2,335 parts per million at Ingleside, in spite of dilution at that point. Reports of the drillers indicate that stronger waters, probably as high as 3,000–4,000 parts, are commonly found in this zone.

The origin of the high salinity of this zone is probably climatic, the area at present lying in the dry half of the sub-humid zone where evaporation exceeds precipitation (Thornthwaite, 1931; Price, 1933a, 1933b). In addition to concentration of the salts of normal groundwater by evaporation, oceanic salts are brought inland by fog droplets and by spray blown miles inland during tropical hurricanes which occur on this coast. In opposition to an origin under the present climate is the fact that saline playas are not characteristic of the subhumid zone of this area, but of the semi-arid zone (Price, 1933b). If concentration of ground waters were now occurring here, saline ponds might be expected. Shallow playas which formerly occurred on the upland of this area, but which have now been drained and cultivated, showed soil which was alkaline but not too strongly alkaline to prevent crops from growing, although poorly, on them. The writer has previously presented evidence which suggests that there may have been a former, more northerly extension of the semi-arid zone,[8] but

[8] The extension of the Goliad caliche to Guadalupe River through what is now the drier half of the sub-humid zone. Caliche may be a product of the semi-arid zone (Price, 1933a).

the time of this postulated extension has not been fixed. There may have been several major climatic cycles since that time.

As is seen from Figure 2, potable waters, grading into non-potable saline waters, occur at various horizons in the Pleistocene beds of the area. The potable waters are those having less than 2,000 parts of chlorine. Less palatable waters now used in the area contain as much as 6,200 parts per million of chlorine, although only a very few wells, used for stock watering, are in use with chlorine in greater proportion than 4,000 parts.

There is no evidence from the data available that there is a regular vertical gradient of chlorine within the Beaumont-Lissie which is typical for the area, below the shallow zone of high content of chlorine.

The strongest chlorine content for the area is reported from the wells formerly in use in Artesian Park, in the town of Corpus Christi. These wells have been abandoned for many years because of corrosion of the pipe. They were formerly in use for their supposed medicinal value. An analysis of a sample from one of these wells, probably the original one, follows.

ARTESIAN WELL, ARTESIAN PARK, CORPUS CHRISTI, TEXAS*

Geological and Agricultural Bureau, Austin, Texas

March 4, 1860. Sampled February 18, 1860. W. P. Riddle, analyst. B. F. Shumard, State geologist.

Hydrogen sulphide odor, saline taste; calcareous sediment in flask. Sp. g. 1.01439. Traces of bromine and iodine.

	Parts per 100,000	*Parts per Million*
Sodium chloride	1,464.4689	
Calcium chloride	109.6242	*Cl* 9,578
Potassium chloride	4.5831	
Calcium sulphate	14.9238	
Sodium sulphate	5.7862	
Potassium sulphate	1.2136	
Aluminum sulphate	13.5605	
Magnesium sulphate	6.2962	
Carbonates of sodium and potassium	118.1165	
Total	1,738.5730	

* Data from *The Corpus Christi Ranchero* (March 31, 1860). The well is supposed to have been about 500 feet deep.

Although no regular gradient of chlorine has been found in a vertical direction within the Lissie-Beaumont group beneath the zone of shallow saline ground water, there is a regular increase in chlorine concentration down the dip, which has sometimes been referred to by writers as "the vertical direction."

FLOWING WELLS

Flowing wells of potable water are common in only a few parts of the area. Most of these seem to have been drilled to depths of

900–1,200 feet and may be from sands below the Beaumont. Below the Lissie, down to 6,000 feet or more, many sands yield flowing waters which are strong brines, some containing hydrogen sulphide. A few sands below the Lissie seem to contain sweet sulphur water without noticeable saline taste, but none of these sands has been tested.

The following groups of flowing wells are reported: west of Bishop in the Palo Alto subdivision, at 850–900 feet; a well on the Luby Ranch near Petronilla Creek flowing from 1,100 feet or deeper (this vicinity formerly had several such wells); a flowing well on the Welder Ranch near Angelita, at a reported depth of about 280 feet; flowing wells on another Welder Ranch (Fig. 2) just north of Sinton, at depths of approximately 900 feet; one of the Sinton town wells flowing 45 gallons a minute from a depth of 932 feet, and raising the water into a standpipe; a flowing well at the Copano Club, south shore of Copano Bay; one at Ingleside between 500 and 1,750 feet deep; and wells at Artesian Park, Corpus Christi, from 500 to 1,600 feet, strongly saline and sulphurous.

RANGE OF CHLORINE, SULPHATE, AND CARBONATE RADICALS

In 1932, when the former article on this survey was written, the regional gradients of chlorine had not been studied. In the light of the regional picture, the ranges of dissolved substances given in that article for the waters of different formations are seen not to be truly representative (Price, 1932, pp. 389-90, Tables II–IV). The figures in Table II are believed to represent the ranges for the Beaumont-Lissie sands more correctly. Other formations are not surely placed in the wells, and no attempt is made to allocate analyses to them.

TABLE II

ZONES OF BEAUMONT-LISSIE WATERS*
(Parts per Million by Weight)

		Cl	SO_4	HCO_3	*Total Depth, Feet*
1. Near-surface fresh waters in Beaumont beneath dune-sand ridges	Low	90	Trace	230	40
	High	240	Trace	435	100
2. Near-surface zone of saline waters	Diluted	2,335	95	357	76
3. Main Beaumont-Lissie waters, beneath surficial zones	Normal: Low	300	210	120	100
	High	4,620	1,080	400	1,200
	Maximum found	9,578	2,350	811	1,200

* Excepting for the well at 76 feet, the horizontal lines of figures are taken from different analyses. The carbonates found were, in all cases, bicarbonates. "Normal" waters (Zone 3) are those from the area where regional isosalinity lines have been drawn and from between local anomalies.

PLEISTOCENE STRATIGRAPHY OF CORPUS CHRISTI AREA

The stratigraphic geology of the South Texas Gulf Coast has been described by Deussen (1924) and by Plummer (1933). The lithologic character of the Beaumont and Lissie for this immediate area has recently been discussed by the writer (Price, 1934), who has also described the physiographic features (1933b).

The Beaumont and Lissie together form the Houston group of Plummer. The Beaumont is composed dominantly of gray and tan clays, and the Lissie of sand, with fine-to-coarse gravel. Beaumont sands lack gravel and are fine grained. Clay of the Beaumont type occurs in the Lissie. Some beds of consolidated (mature) caliche occur in the Lissie (Price, 1933a). Calcareous nodules (young caliche) are characteristic of the weathered zone of the Beaumont. The two formations have not been differentiated in well sections in this area, both being somewhat lenticular and the well records being too inaccurate for correlation purposes. The total thickness of the two here is probably as great as 1,200 feet.

The Beaumont contains oyster shells and *Foraminifera* near the coast and here and there throughout its area. Non-fossiliferous tan clays contain much selenite in small crystals. Marine shells in the Lissie are reported from some wells near the coast. The Lissie contains scattered vertebrate bones, land snails, and fragments of leaves. Some vertebrate remains are found in the Beaumont.

The Lissie is believed to be chiefly fluviatile and deltaic, the coarse gravel and large volume of sand having necessitated an exceptional amount of precipitation for its transportation (Plummer, 1933). The Beaumont is the product of quieter stream run-off forming deltaic deposits of sand and clay with lagoonal and marine clays and at least one sandy beach bed (Price, 1934). It is believed to be more lenticular than the Lissie.

Study of cross sections based on water sands has inclined some geologists to regard the upper 400 feet of sediments in this area as flat-lying, or as having a dip no greater than that of the upland prairie, that is, 2.5–3 feet per mile. According to this view, these upper beds comprise the entire Beaumont, the Lissie containing the underlying sandy beds with a distinctly greater, although low, dip and with more continuous water sands. The data on water sands for these cross sections were obtained by direct measurement of well depths.

Under the Lissie lies the Goliad formation of coarse sands and gravel with interbedded clay (Plummer, 1933, pp. 750-60). The sands

are heavily impregnated with caliche at the outcrop. The thickness of the Goliad is estimated to be 250 feet in the outcrop area. Beneath the Beaumont, the Goliad has not been separated from the Lissie in this area, because of inadequate well records. At present no strata above the *Discorbis* marine zone of the Oligocene may be satisfactorily correlated in this area, on the basis of the data available. The Goliad is regarded as Pliocene in age, but according to data which seem meager. The Pleistocene does not contain petroleum in this area, but small amounts of natural gas occur in its sands.

PLEISTOCENE CLIMATES AND SEA-LEVELS IN SOUTH TEXAS

It is now rather generally believed by geologists that oscillations of sea-level accompanied the advances and retreats of the northern continental ice sheets of the Pleistocene Ice age. These oscillations were caused by the transfer of great volumes of water from ocean to ice cap and into water again. There were six major advances of the northern ice, which should have caused six lowerings of sea-level. Six low-level and seven high-level positions of the shore line are also required by theory. Cooke (1931) has announced the finding of seven coastal terraces in the southeastern states at 25, 42, 70, 100, 170, 215, and 270 feet, respectively, above present sea-level.

The writer does not agree with Cooke in finding so many high-level marine terraces in South Texas, there being only one demonstrated within the Beaumont outcrop (Price, 1933b, Ingleside Terrace, scarp 12–25 feet above sea), the Beaumont Terrace or deltaic plain, the inner edge of which probably represents a marine shoreline, and two or more terraces on the Lissie and Goliad outcrop areas which are not conclusively demonstrated to have been of marine origin (Alice and Realitos terraces of Deussen, 1924, Pl. I). However, the low-level positions of the shore line, now buried by marine deposits, mark former land surfaces within the Beaumont-Lissie sediments. Other, high-level shore lines formed during the Pleistocene on the South Texas deltaic coastal plain (Barton, 1930) are probably obscured by deltaic deposits. The scarps in the Beaumont outcrop area which Cooke considered marine terraces (at 42, 70, and 100 feet) are discontinuous and include slopes on the flanks or ends of remnants of ancient distributary ridges of the delta streams.

Antevs (1928) shows that a reasonable explanation for the accumulation of a Pleistocene ice sheet involves an increase of precipitation in polar regions, but that an accompanying decrease in precipitation in the equatorial regions is an equally reasonable postulate. However, he also finds that a decrease in temperature would have

occurred along with the decrease in precipitation (Antevs, 1928, pp. 32-33).

Based on the foregoing reasoning with regard to sea-level oscillations and climatic cycles accompanying the advances and retreats of Pleistocene ice sheets of the northern hemisphere, the following generalized, ideal sequence of events for South Texas, for a period of ice advance in the north, followed by the succeeding inter-glacial period of ice retreat may be proposed.

TABLE III

THEORETICAL SEQUENCE OF EVENTS IN SOUTH TEXAS DURING A PLEISTOCENE CYCLE OF ICE ADVANCE IN THE NORTH

Period of maximum ice advance.—Fall of sea level. Contraction of arid zones; cool, dry semi-arid climate. Reduced rainfall, but reduced evaporation and summer temperatures; hence, moister conditions than today. Torrential rains and meager vegetative cover; soil erosion. Meander loops of streams are broader than in previous period (Barton, 1933a, pp. 381–82). Alternation of coarse and fine sediments; gravels occur. Extensive land surface; soils calcareous, caliche development not prominent; soils, gray-to-light brown-to-black in color (Price 1933a, p. 500). Shallow ground waters are fresh; water table high. Area of marine deposition shifted seaward; deltaic deposits extended across newly exposed coastal plain; rivers entrench themselves in old plain in canyons; erosion of inter-stream plains limited. Marine planation of coastward parts of last previously formed deposits; low-level marine terrace and low-level deltas resulting.

Period of maximum ice retreat.—Rise of sea-level. Expansion of arid zones; warm, semi-arid climate; increase in summer temperature and evaporation; rainfall perhaps as to-day. Reduced run-off? Torrential rains occasional. Contrast between coarse and fine sediments occurs, but less marked? Land surface reduced; soils calcareous ("lime" accumulating), black-to-gray with caliche in sub-soil (Price, 1933a), beds of consolidated caliche developed with prolonged exposure and mature leaching. Shallow ground waters are saline; water table low. Area of marine deposition shifted landward; drowning and silting-up of entrenched valleys, with formation of bays by marine planation in estuaries. Development of deltaic deposits largely limited to valley deltas. Formation of high-level marine terraces and high-level deltas with burial of low-level terraces.

Cool semi-arid climate may vary to cool humid with sesquioxides replacing caliche in red and brown soils. Warm semi-arid may vary to hot, arid climate.

REGIONAL STRUCTURE OF SOUTH TEXAS COASTAL PLAIN

The Beaumont, Lissie, and Goliad, with the underlying beds of the Tertiary, have, in general, a homoclinal dip toward the coast (Deussen, 1924).

Major anticlinal and synclinal axes of warping trend across the strike of this homocline, and have been mapped by Stephenson (1926, 1928) from the outcrops of the Cretaceous and of the early Tertiary rocks and projected through the younger beds to the gulf shore line, which they are shown to meet perpendicularly. Some progress in mapping the coastward extensions of these axes by subsurface data is reported.

The Corpus Christi area lies midway between two of these axes, the Nueces geosyncline (Plummer, 1933, Fig. 28), formerly known as the Rio Grande embayment, and an anticlinal, or up-warp, axis, the

San Marcos arch (Plummer, 1933, p. 526) which extends southeastward from the Llano uplift. The Nueces geosyncline axis reaches the coast probably at some point south of Baffin Bay and the up-warp axis near Lavaca or San Antonio Bay (Stephenson, 1928, Fig. 1; Barton, 1933c, Fig. 6).

Stephenson reports the geologic section to be, in general, thinner on the trans-coastal up-warps than on the down-warps, because of thinning of beds on the up-warps and absence of some beds there.

Barton has recently postulated the existence of a geosynclinal basin of thick sediments with its axis along the gulf shore line from the Corpus Christi area to northwestern Florida. The basis of this assumption is the gravity data (Barton, 1933a, 1933e).

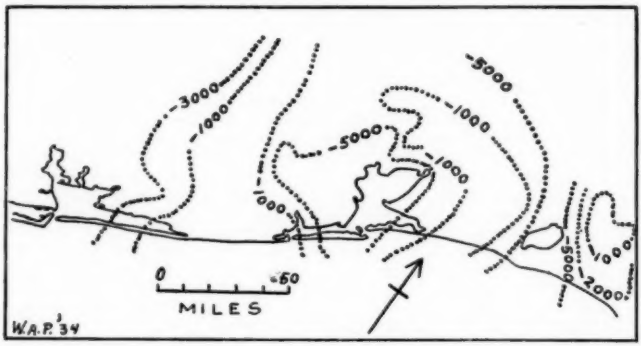

FIG. 4.—Are Texas bays located in structural depressions? Contours show depths below sea-level to tops of salt-dome cores (cap rock or salt), after Barton (1933b, Fig. 5). Galveston Bay lies near the arrow; Sabine Lake, 50 miles northeast; and Matagorda Bay, 75 miles southwest. Lavaca Bay is longest arm of Matagorda Bay on its inland side.

DO TEXAS BAYS LIE IN STRUCTURAL BASINS?

Contours drawn on the basis of the sub-sea depths of the tops of the Gulf Coast salt-dome cores—cap rock or salt—show areas of high-dome and areas of low-dome tops. Using these data, Barton has described the Iberian structural axis which trends northwest and southeast in southern Louisiana, paralleling the lower course of Mississippi River (Barton, 1933d).

Barton finds a topographic ridge along his Iberian axis. This ridge is evidenced by dry land surrounded by marsh. He also finds that certain adjustments of drainage have occurred in the vicinity of the ridge which he interprets as due to arching along it. The top-of-salt-core contours along this ridge show depths of 500 feet below sea-level

along the axis to 5,000 feet along the flank (Barton, 1933d, Fig. 1; 1933b, Fig. 5). Thus, elevated salt cores seem to indicate an upwarped structure.

If Barton's interpretation may be applied, in reverse, to areas of relatively low salt cores, the top-of-salt contours (Fig. 4) indicate[9] that the major bays of the Texas-Louisiana coastal salt-dome area lie in structural basins. These are Sabine Lake, Galveston Bay, and Matagorda Bay.

According to the foregoing interpretation, Sabine Lake lies in a narrow trough, with salt domes near by at 5,000 feet below sea; Galveston Bay lies in the northeastern half of a large basin which extends to Houston and to the Brazos River group of salt domes; the known salt domes begin to descend on the southwest as Matagorda Bay is approached from the east.

The thesis of the present paper, that is, that the chlorine gradient from the land toward the Nueces-Corpus Christi geographic embayment indicates a structural basin with these conjoined bays lying along its northern half, agrees with the interpretation of the top-of-salt-core contours in showing the occurrence of the bays of Texas in structural basins. Whether or not these basins connect landward with trans-coastal-plain down-warp axes is not evident in the data. The adequacy of salt-core contours to indicate regional structure is not here debated.

There is some evidence that the isosalinity lines bend inland around Lavaca Bay, according to a preliminary study of data, which are said to be rather scanty, collected for the United States Geological Survey. Lonsdale, who contributes this information, says that the difficulty of making a more definite statement at this time lies in the scarcity of wells drilled to the same set of sands and of wells that have no casing leaks.[10] The writer is inclined to consider such indications important, provided the number of wells is large and the distribution of wells from the different levels is approximately uniform. No precision is expected from such data, but the general picture should emerge in spite of their shortcomings. Lonsdale's information suggests a basin structure for Lavaca Bay.

LOCAL CHLORINE ANOMALIES

When isosalinity lines are drawn through the chlorine values obtained by analysis for the wells shown in Figure 1, it is found that there are many more or less oval areas of locally high chlorine with

[9] Orally suggested by Barton as a possibility.

[10] J. T. Lonsdale, letter of December 6, 1934.

low-chlorine closures scattered between the high closures. These local variations are referred to as *anomalies*. For convenience, the anomaly is considered to center at the high-chlorine closure and to extend to the adjacent "lows."

In East Texas, such local anomalies of high chlorine are associated, in the Woodbine sand, with oil-bearing structural traps. Although too little is yet known of the local structural details of the water-well-survey area of Figure 1 to demonstrate the degree of correlation between anomalies and local structure, a few remarks on this subject are, perhaps, not inappropriate.

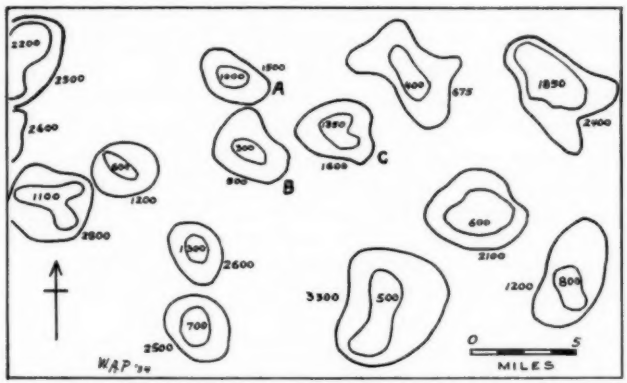

FIG. 5.—Pattern of local anomalies of high chlorine in a part of Corpus Christi area. Inner lines show areas of closure; inner figures, amount of closure. Outer lines show total areas of anomalies; outer figures total relief. Figures in parts per million. Waters sampled from Pleistocene. Anomalies *A*, *B* and *C* based on one well each and are to be disregarded.

A large anomaly is associated with the Agua Dulce field of Nueces County. Its closure lies on and just east of the axis of the structure in the shallow gas sands, and the anomaly extends down the southeast flank beyond the limits of the field.

A large anomaly lies near the White Point field of San Patricio County and may cover it, although there are no water wells in the area of the field, because of the high salinity of waters found in early attempts to get water for farm use.

The East Texas local anomalies of the Woodbine show sharp, linear western boundaries where the isosalinity lines close against the bounding faults which cut the Woodbine itself. In the present survey, the water sands lie several thousand feet above the oil and gas sands

of the area and may not be cut by such faults as cut the oil and gas sands. The anomalies here do not show sharp, linear boundaries; nor do they show linear alignments of groups of anomalies, but are suggestive of the alternating anticlines and synclines of the Appalachian region which occur in an approximately quincunx pattern.[11]

The interpretation of the occurrence of local anomalies on structure in the Mexia-Powell line of oil pools is that the fault traps acted as dams to retard the dilution of the connate waters behind the faults by the fresh waters flowing down the dip of the sand. The anomalies of the Corpus Christi area are what might be expected if structural traps with low-flank dips in the Pleistocene sands caused a retardation of dilution of the original brines on the down-dip sides of these gentle structures.

In opposition to this interpretation of the local anomalies, or modifying it, is the composite nature of the anomalies of the present survey, representing analyses in sands at several depths. However, each sand containing waters which are being diluted by down-dip flow should show such an anomaly in the same position on a given structure. It is also to be expected that lenses of tight sand and lenses of clay within a sand body would also act as dams in obstructing down-dip flow, and therefore produce anomalies of some type.

Plummer has suggested,[12] from studies of another area, now in progress, that waters may be evaporated slowly in areas of maximum pressure associated with folding and uplift, and move, as vapors, to areas of lesser pressure. Such a process would leave the solutions more concentrated in areas of greater pressure and less concentrated in areas of lesser pressure, but whether it could be applied to explain lateral variations in concentration in a given formation or sand in an area of gentle folding, such as this, is problematical.

REGIONAL ISOSALINITY LINES

The chlorine data are not presented in detail in this paper, but a regional picture of the variations in chlorine content across the area, after elimination of the local anomalies, is presented in Figure 2.

The change from low to high chlorine is evident in the data, whether average, maximum, or minimum salinities of groups of wells are considered. In constructing the regional, smoothed-out isosalinity lines of Figure 2, the detailed isosalinity lines were carefully inspected. The line of 2,000 parts was found to be continuous throughout the area, excepting where it crosses narrow areas without water wells.

[11] That is, like the 5 dots on the face of the 5-spot side of dice.

[12] F. B. Plummer, letter of October 25, 1934.

The smoothed-out line follows the actual line closely, not departing from it more than 2 or 3 miles at any point.

The lines of 3,000 and 4,000 parts are evidently essentially parallel with the 2,000 line. They may actually lie a little farther east than the positions shown, but scarcity of wells with these high salinities did not permit a wholly accurate placing of these lines.

The 1,000 and 500 lines actually depart somewhat widely from the positions assigned to them in Figure 2. These positions have been determined by the points of closest approach of these lines to the 2,000 line. A smooth line was drawn, in each case, through these points of closest approach to obtain the regional isosalinity lines of 500 and 1,000.

INTERPRETATION OF REGIONAL SALINITY UNDER FAVORED HYPOTHESIS

Before possible alternative hypotheses are considered, an attempt is made to interpret the courses of the regional isosalinity lines of the area on the basis of the favored hypothesis that the salinity gradients observed are the result of the mixing of surface waters entering at the outcrop with indigenous brines whose concentrations were higher than any now found in the wells sampled.

The surface waters are presumed to have flowed down the dip of the sands and sandy zones at an approximately uniform rate from all points along the outcrop. This flow was somewhat retarded by local structural and lithologic irregularities, producing local anomalies of high chlorine. The anomalies caused by structural dams should be more regular in form than those caused by lithologic variations because the former should prove to be similar in all Pleistocene sands whose waters are receiving additions at the surface, while the latter should produce anomalies which would differ in size, shape, and position in different sands.

The courses of the isosalinity lines in Figure 2 are conspicuous for the following features.

A. Parallelism of the lines; salinity increasing toward the gulf and the bays
B. Acceleration in gradient toward the water areas
C. The lines north of Corpus Christi Bay are parallel with the gulf shore line
D. Bending of lines around Corpus Christi-Nueces Bay
E. Occurrence of a "nose" in the isosalinity lines north of Corpus Christi Bay
F. An area of low salinity along the dune-sand ridge of Live Oak mature offshore bar

A. A strong resemblance is shown in these features to the East Texas Woodbine regional salinity picture (Fig. 1). The extent of the resemblance suggests a similar history of the evolution of the waters.

B. There seems to be an acceleration of the salinity gradient toward the water areas. Since so few isosalinity lines may be drawn, however, the true rate of acceleration and its significance can not be determined.

C. Parallelism of the isosalinity lines with the gulf shore line, where it occurs, indicates a resumption of the normal homoclinal dip, under the favored hypothesis.

D. This bend is regarded as indicating a structural basin or downwarp with its east-west axis approximately through the vicinity of the Agua Dulce field and the town of Corpus Christi, and sloping eastward. This is termed the Corpus Christi structural basin.

E. The axis of this nose runs from a point 3 miles north of Sinton through Ingleside and the south end of Live Oak Ridge.

F. This reservoir of fresh water, already described, bears no relation to the regional chlorine gradients of the Beaumont-Lissie sands which lie below the shallow surface zone. Data from deeper wells, if available, should enable us to draw isosalinity lines of concentrations greater than 4,000 beneath this dune-sand ridge. The occurrence of this reservoir shows that surface waters can penetrate into the lenticular sands of the upper Beaumont if provided with adequate pressure.

EVIDENCE FROM PHYSIOGRAPHY

The deltaic character of the upper surface of the Beaumont has been noted. The writer has previously described the ancient delta of Nueces River[13] (Price, 1933b, pp. 922-24, Fig. 3), as marked by its distributary ridges. Between White Point field and Robstown the delta is 15 miles wide and seems to have extended upstream with essentially the same width. In 15 miles downstream, however, it widens to a front of 60 miles along the inner shore of the Ingleside Terrace, from the south end of Copano Bay to the upper end of Alazan Bay, a branch estuary of Baffin Bay (Fig. 3).

This ancient delta was, so far as is known, partly of subaërial origin. Its upper surface is now elevated, along its central axis, about 15 feet above adjacent parts of the Beaumont deltaic plain. The high bluffs at Corpus Christi occur on the axis of this delta, at the summit of the depositional "high."

The delta is closely related in position to the postulated structural basin. The expanded front of the delta lies outside the basin, at least at the north. The distributary ridges of this expanded part extend

[13] This is the Atascosa-Nueces delta. The present course of the upper Nueces is believed to be approximately that of a stream (the ancient Baffin-Nueces) which flowed into Baffin Bay before its capture by a branch of the Frio-Atascosa-Nueces system.

along the regional strike as determined by isosalinity lines. The axis of the delta coincides with that of the postulated basin.

The indicated adjustment of the delta to the basin occurred prior to the entrenchment of the river. The age of the basin, according to this reasoning, would antedate the arrival of the Live Oak offshore bar at the coast line and the formation of the Ingleside Terrace deposits (Price, 1933b, p. 929).

Following the Ingleside Terrace period, the sea-level fell, and canyons at least 50–75 feet in depth were cut by the rivers through the delta deposits and across the Ingleside Terrace. After the return of sea-level to its present position, 10 feet below its former high-level elevation, the canyons were drowned, their deeper parts filled with silt, and their upper parts widened by marine planation to produce the present bays. These bays have shallow, pan-like, topographic basins 8–16 feet in maximum depth (Price, 1933b, p. 929).

The present topographic basin of Corpus Christi and Nueces bays lies north of the center of the postulated Corpus Christi structural basin. Such a position is to be expected from the known direction of the dominant wind which blows strongly for 9 months from the southeast. The north shores should, in this area, recede faster than south shores in marine planation.

More rapid retreat of shore lines on the north is indicated also by somewhat straighter southern shore lines, and by a more extensive preservation of river terraces on the south, with the northern shores somewhat more marked by steep bluffs and reëntrants. The up-stream head of the Corpus Christi-Nueces embayment is believed to have been at Calallen, where a gently sloping river terrace emerges from beneath flood-plain deposits. Bay-head filling has resulted from the growth of the valley delta of Nueces River (Price, 1933b, p. 941).

There seems, thus, to have been an adjustment in position of the ancient Nueces Delta, the entrenched Nueces River, and the Corpus Christi-Nueces geographic embayment to the postulated Corpus Christi structural basin.

LACK OF CONFLICT WITH STRUCTURAL DATA

As this is written,[14] there seems to be no conflict, within the area of the water-well survey, between the conception of a structural basin as here outlined and the existing subsurface structural data. Figure 1 shows the currently accepted sub-sea depths to the horizon of the top of the *Heterostegina* zone (Deussen, 1934, p. 501, Table I) of the Oligocene (Miocene?). These figures include some from wells for

[14] December 4, 1934.

which the position of the zone has been determined by correlation, the fossils not having been found. For producing fields only the highest and lowest figures are given, where appreciable relief is indicated. The validity of these data is not discussed. They are probably reasonably accurate for the purpose of this study.

Any attempt to check the postulate of a structural basin from these data is open to the serious criticism that the sub-surface data include points both on and off structure and that the structural position of the non-productive wells can not yet be determined or the lowest contour present around a producing area known. The known structural relief in the Saxet pool is about 500 feet.

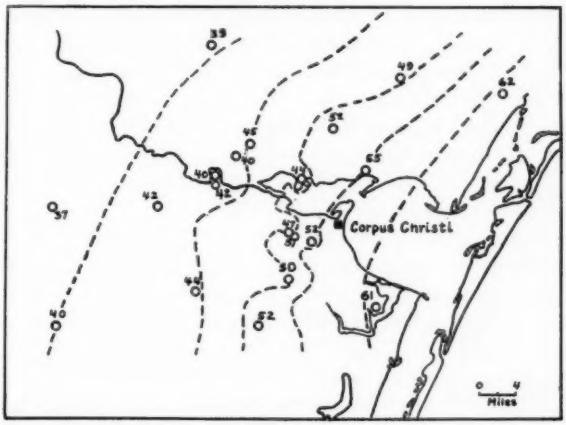

FIG. 6.—Interpretation of available subsurface control on *Heterostegina* zone. Figures show nearest 100-foot depths below sea-level for oil and gas test wells of Figure 1. Contours are based on assumed "normal" positions of top of *Heterostegina* zone as indicated by non-productive wells and by 500-foot relief at Saxet. The data do not seem to necessitate adoption of either an anticlinal or a synclinal regional structure for Nueces River and Corpus Christi-Nueces Bay at *Heterostegina* horizon.

A tentative subsurface structure map (Fig. 6) for the area has been constructed, using the non-productive wells as indicative of the positions of regional contours and bending the contours around producing fields and a few probable structures. The local structural relief may be as great as the contour interval used. No prominent regional features appear on this map.

More complete data might modify this map in either direction, toward either a dominantly anticlinal or a dominantly synclinal area along the lower Nueces drainage and the area of the bays.

The subsurface data available seem not to oppose any objection to the existence of a down-warp in the Pleistocene beds, 4,000 feet above this *Heterostegina* marker zone. Neither does this map preclude the existence of an up-warp farther up Nueces River, if its southeast nose extends only as far coastward as the upper end of Nueces Bay, where it might die out as a detail of the outline of the larger structural basin. Some geologists state that their work indicates that such an up-warp does exist farther up the river.

FAVORED HYPOTHESIS OF DOWN-DIP FLOW OF SURFACE WATERS

The tentative interpretations previously offered in this study of the distribution and gradients of salinity as revealed by this survey (Fig. 2) have been based on the postulate of the approximately equal entry of fresh surface waters into the outcrop of the Pleistocene water sands and their equal flow down the dip from all points.

This process should result in essential parallelism between regional structural contours and regional isosalinity lines in basins of relatively uniform and gentle slope, such as the East Texas basin (Fig. 1) and any basin which may exist in the Corpus Christi area in the shallow formations.

The process also requires that the incoming fresh waters shall mix with brines of somewhat uniform salinity and that this salinity should have been greater, prior to this mixing, than that now found at any point by the survey. Any possible addition of chlorine salts to the waters from below or picked up from the sediments by descending solutions must have occurred in a relatively uniform manner.

Aside from the resemblance of the Corpus Christi regional salinity map to that of the East Texas basin, where the subsurface contours are known to parallel the isosalinity lines, the conditions chiefly favoring this hypothesis are the following.

A. The suggestion of widespread dilution of brines, as seen in the entire absence of any waters of oceanic salinity in the area studied (Fig. 2).

B. Parallelism of the isosalinity lines with the gulf shore line north of Corpus Christi Bay, thus duplicating the structural picture which would result if a basin did occur, as postulated, as a detail of the known homoclinal slope.

C. Adjustment of the physiographic features, that is, river delta, entrenched stream, and wind-eroded bay, to the postulated basin (Fig. 3).

D. The supporting data suggesting that Texas bays lie in structural depressions (Fig. 4).

E. The rhythmical alternation of bays along the coast which would be as well in accord with a succession of up-warps and down-warps as with a succession of drainage basins of sub-equal size.

F. The resemblance of the pattern of the local anomalies of high chlorine to a structural, rather than to a shore-line, pattern (Fig. 5).

It is not claimed that the evidence here assembled is more than suggestive. The writer believes that the evidence favors this inter-

pretation, however, rather strongly, in view of the absence of alternative hypotheses which, in the light of present knowledge, can be advanced with much plausibility.

EVOLUTION OF MIXED WATERS OF COASTAL PLAIN AQUIFERS WITH REFERENCE TO THEIR CHLORINE CONCENTRATION

Before hypotheses opposed to the one here suggested are considered, it is necessary to make a theoretical study of the possible cases in which waters of different types become mixed in the aquifers so as to produce regionally uniform gradients of chlorine increasing in salinity seaward.

The ascent of strong brines from buried deposits of rock salt is not considered a factor in the production of regional salinity gradients because, in East Texas, it seems to have had a merely local effect, and because, in the Corpus Christi area, no sharp contrasts between salinities on and off the local anomalies are present and no straight-line contacts between high and low salinities are found (Fig. 5).

The numerous oscillations of sea-level during Pleistocene time, resulting in great horizontal movements of the shore lines on a coastal plain of low slope, must have resulted in the formation of a complex series of deposits of marine, lagoonal, estuarine, fluviatile, deltaic, alluvial, and residual origins. These must have been truncated at many points and levels by marine planation. Although subaërial erosion of the plain was probably slight during this time, sharp entrenchment of streams occurred, resulting in narrow canyons being formed and subsequently filled with boulders and silt.[15]

The difficulty in unravelling this history in detail by subsurface correlation in formations devoid of key beds or fossils is apparent.

It is also evident that the history of the connate brines of this series of deposits may have been relatively complex and that mixing with waters later entering the strata may have occurred in several ways. It is possible to imagine several ways in which such mixing may have occurred in the aquifers so as to produce salinity gradients of a uniform type.

Table IV has been made to assist in the analysis of the theoretical evolution of mixed waters in artesian aquifers of coastal plains. Com-

[15] The submerged canyons through Copano Bay revealed by coring along the causeway on the Hug-the-Coast Highway are filled with silt (Price, 1933b). Water-well studies along the lower Rio Grande show a water-bearing boulder bed which is probably an ancient canyon. The boulders are reported, by J. T. Lonsdale, from an area where the Goliad sandstones would have furnished boulders to a canyon cut through them. Rio Grande is competent to have brought boulders down from areas far up-stream as well.

TABLE IV

THEORETICAL DEVELOPMENT OF CHLORINE GRADIENTS OF MIXED WATERS IN ARTESIAN AQUIFERS

I. CONNATE BRINES—Oceanic; lagoonal; saline lacustrine; saline ground water of arid-zone soils

1. *Down-dip increase in chlorine gradient from potable waters to brines*

A. OUTCROPPING AQUIFERS

a. Aquifer receiving fresh surface water through outcrop during humid period
Examples: East Texas structural basin, Corpus Christi structural basin (Figure 7, *a*)

B. BURIED AQUIFERS

b. Up-dip end of aquifer near surface of ground; receiving surface water through cap by infiltration from elevated fresh-water reservoir in offshore bar, beach ridge, or distributary ridge during humid period
Examples: Late Pleistocene sands under offshore bar of Netherlands coast; youngest Beaumont sands under Live Oak uplifted offshore bar, South Texas (Figure 7, *b*)

c. Buried aquifer which formerly received fresh surface water through outcrop on a former land surface, or from an elevated reservoir now buried, or removed by erosion (Figure 7, *c*)

2. *No regular up-dip or down-dip increase in chlorine gradient*

B. BURIED AQUIFERS

d. Aquifer has never cropped out or received fresh surface water (Figure 7, *d*)

II. CONNATE FRESH SURFACE WATERS—Waters of alluvial and deltaic deposits of humid lands; lacustrine and soil waters of humid lands

3. *Up-dip increase in chlorine*

A'. OUTCROPPING AQUIFERS—or those which once cropped out

e. Aquifer originally contained fresh surface water of humid climate; strong evaporation under arid climate depleted the ground water in outcrop, lowering water table, with accompanying concentration of dissolved salts and accumulation of brine in up-dip end of aquifer (Figure 7, *e*)

f. Conditions like *e*; a later marine invasion filled up-dip end of aquifer with brine, mixing with saline ground waters (Figure 7, *f*)

Down-dip increase in chlorine gradient from potable waters to brines

AA'. OUTCROPPING AQUIFERS—or those which once cropped out

g. Conditions like *e*, but without important concentration of ground-water salts in up-dip end of aquifer; fall of sea-level causes marine planation or stream entrenchment to lay bare lower parts of aquifer to marine waters; marine waters enter aquifer and flow up-dip to balance lowered hydrostatic pressure resulting from loss of water at outcrop by evaporation (Figure 7, *g*)

4. *Potable waters between up-dip and down-dip areas of brine*

AA'. OUTCROPPING AQUIFERS—or those which once cropped out.

h. Conditions and history as in *g*, but important concentration of ground-water salts did occur in up-dip end of aquifer before fall of sea-level (Figure 7, *h*)

2. *No regular up-dip or down-dip increase in chlorine gradient*

AB. OUTCROPPING OR BURIED AQUIFERS

i. Aquifer under humid climate since deposition or until burial; no entry of brine at lower end (Figure 7, *i*)

III. CONNATE FRESH WATERS AND CONNATE BRINES—Oceanic; lagoonal; estuarine (bay); fluviatile and fresh ground water of humid zone

1. *Down-dip increase in chlorine gradient from potable waters to brines*

AB. OUTCROPPING OR BURIED AQUIFERS

j. Connate waters of aquifer vary from marine to fluviatile through normal sequence for young shore lines of emergence where deep embayment is also present, as on Texas coast of to-day; that is, sequence of ground waters from coastward positions inland may, in some areas, range from marine and highly saline lagoonal brines, to dilute bay and fresh fluviatile waters; the aquifer is also receiving, or received before burial, fresh surface water of humid zone through outcrop (Figure 7, *j*)

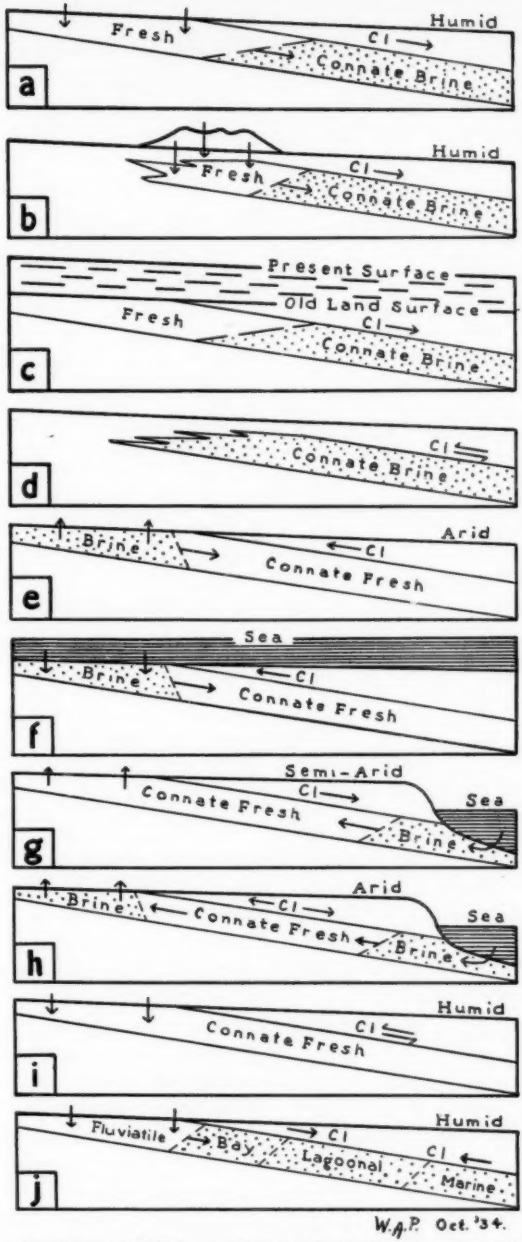

FIG. 7.—Evolution of chlorine content of mixed waters in coastal-plain aquifers. Unmarked arrows show directions of movement of waters; arrows with *Cl* show directions of increase in chlorine concentration; opposing arrows superimposed show absence of uniformity in chlorine gradient. Dotted stipple indicates brine. Contacts between waters shown sharp, but diffusion and variations in lithologic character produce intergradations and irregularities of contacts. For description of details see Table IV.

binations of the simple cases here presented may be imagined. The ten cases described in the tabulation are illustrated by diagrams (Fig. 7, a-j).

In the preparation of this table, the entry of surface waters into the up-dip end of an aquifer containing connate brines has been given a position of major importance in the production of the mixed waters, and the entry of marine waters into strata after their deposition one of subordinate importance. No importance is assigned to post-depositional seepage from the gulf and bay waters into any but very shallow beds—and this only under very special conditions—as it is not believed to be at all likely that general downward penetration of marine waters is possible through the capping strata of artesian aquifers into deeply buried strata because such waters would be moving downward from areas of less pressure into areas of greater pressure.

The possible production of regional chlorine gradients in unmixed waters through the operation of such depth factors as temperature, pressure, and compaction of strata, being wholly theoretical as to both their possible qualitative and quantitative effects, has not been considered in the tabulation, but is briefly discussed in consideration of alternative hypotheses.

The chemical evolution of the waters is not here considered, since the analyses of the study were incomplete and since, of the radicals determined thereby, only chlorine has been found to be a suitable index of regional conditions. This study, therefore, is a study of the changes in chlorine concentration which may have occurred during the evolution of mixed waters of coastal plain aquifers.

In the illustrations, the contacts of fresh and salt waters have been shown diagrammatically by straight lines, although diffusion at the contact would be a prominent factor of mixing. Diffusion is considered again under the head of alternative hypotheses.

Features of the theoretical examples of the evolution of waters, which are not discussed in Table IV, but which require consideration, are the quantitative factor and the establishment of equilibrium. Until many regional studies of the salinity gradients of aquifers are available, it will not be possible to determine the importance of some theoretical methods of the mixing of underground waters.

Some students of underground waters stress the surprisingly narrow contact zone between fresh and saline waters, where fresh waters are uppermost. In short-time experiments, and possibly where longer periods are involved, fresh-water layers may rest upon salt-water layers in the shallow ground-water zones, an equilibrium being established between the downward pressure of the fresh water and the re-

sistance of the salt water to displacement by it (Brown, 1925, pp. 20 and 36, Fig. 3).

In *a*, Figure 7 and Table IV, it is believed that deep penetration of the aquifer by surface water will occur, with a uniformly increasing gradient of salinity down to the point of maximum penetration. This penetration will be by flow and diffusion combined.

In *b*, Figure 7 and Table IV, so far as is known from data available, equilibrium will be established between fresh and salt water at a relatively shallow depth under the low hydrostatic head of water in sand dunes and dune ridges, after Herzberg's law (Brown, 1925). If the infiltrating surface water entered a non-saturated stratum, deep penetration down the dip would occur.

In *c*, Figure 7 and Table IV, addition of surface waters would cease when the aquifer was covered with sediments. A deep penetration of the aquifer by surface waters would first have occurred, and a uniform salinity gradient down the dip should result.

In *d* any salinity gradients found would be of connate origin or due to the operation of depth factors or the entry of deep-seated waters along fissures.

In *e* and *h* the amount of brine which might be produced in the outcrop zone is not known to the writer. Where the surface soil is fairly dense, salts will accumulate in playa lakes but lacustrine silts may prevent this saline water from entering the outcrops of beds porous enough to form aquifers. On the outcrops of the porous beds, the soil may, in most places, be porous and allow rain water and flowing surface waters to enter rapidly enough so as not to suffer significant concentration of its mineral content in the zone of evaporation. Some of the salts in the soils of arid regions circulate with cycles of wet and dry weather, being dissolved and carried downward after rains, but some part is precipitated in the soil by evaporation without reaching the water table. In the absence of quantitative data on the problem, the writer is not able to say whether or not the conditions of *e* and *h*, Figure 7 and Table IV, would produce a gradient of salinity for an appreciable distance down the dip of an aquifer.

In *f* the down-dip flow of brine might be appreciable, even in a saturated stratum. The pressure of the entering marine water would depend on the height of sea-level above the outcrop of the aquifer. Down-dip flow would depend on this pressure and the existence of an outlet for the water in the deeper parts of the aquifer.

In *g* and *h* the amount of entry of marine waters would depend on the height of sea-level above the eroded lower parts of the aquifer and the amount and rate of ground-water loss at the outcrop through

evaporation. This is a wholly hypothetical case, no data being available, excepting that heavy withdrawals of water by pumping has been known to cause the entry of sea water at the lower end of an aquifer (Brown, 1925, p. 37, *et seq.*).

The conditions of *j*, if applicable to the Corpus Christi area, would allow, although it would not necessitate, the postulate of basin structure, provided a single aquifer is being considered. In the case of a gradient involving data from superimposed aquifers, superposition of types of connate waters would have to have occurred through repeated invasion of the basin at successive sea-levels, each time with relatively exact superposition of the several types, in order to produce a uniform composite gradient. In such a case, an improbable degree of repetition of shore-line features would seem to be required.

It is, of course, not possible to say that the observed regional chlorine gradient of the Corpus Christi area does not result from the superposition of several aquifers having gradients of this origin (*j*), but such a superposition might reasonably be expected to show pronounced reversals of gradient of regional size, that is, high and low anomalies of chlorine which are continuous across the area, a condition not found.

CASES OF EVOLUTION OF MIXED WATERS APPLICABLE TO CORPUS CHRISTI PLEISTOCENE

In selecting from Table IV cases applicable to the regional picture presented by Figure 2, the writer first approaches the problem from the standpoint of a single aquifer. Since Figure 2 shows a range of chlorine from 200 only as high as 4,000 parts per million, cases in which the chlorine content above 4,000 is not uniform, are included, as well as those in which it is. In addition to a uniform gradient of chlorine in the down-dip direction, a large body of fresh water lying up-dip from a large body of brine in the same aquifer is necessary.

Table IV shows that the requirement of a "down-dip increase in chlorine gradient from potable waters to brines" (sub-head 1) occurs under each of the three major classifications: connate brines, connate fresh surface waters, and connate fresh waters occurring with connate brines. The requirement may also be met in either buried or outcropping aquifers. Thus, the individual cases of Table III which must be considered are: *a*, *b*, *c*, *g*, and *j*.

Until actual examples may be proved to exist, cases need not be considered in which the presumption is strong that one necessary condition is lacking, namely, the occurrence of large bodies of both the original fresh and the original briny waters. Such cases are *b*, where

equilibrium seems to occur before the fresh waters descend for appreciable distances down the dip of the aquifers, and *g*, a wholly hypothetical case in which the mechanism of withdrawal of fresh water by evaporation and the ascent of brine against lessening pressures above is not derived from observation, but from theory.

After the foregoing eliminations, only three types remain, *a* and *c*, which are special cases of the origin by down-dip flow of fresh surface waters mixing with connate brines, and *j*, the case of an original depositional gradient of waters of varying salinity.

When the foregoing selections are considered from the standpoint of the further requirement, to meet the case under study, namely, that similar gradients must occur in each of several superimposed aquifers, and that only local departures can exist from the rule that equal salinities must always occur in the same vertical sections, it is self-evident that the simpler postulate is that connate brines originally saturated the sands and that these have been gradually, and more or less equally, diluted down-dip by surface waters which have entered the outcrop.

In applying these conclusions to the Corpus Christi area, there remains a possible uncertainty as to whether the data secured for the present survey properly depict the regional salinity gradients.

The writer is convinced that the data do depict properly the regional salinities in the Pleistocene group of aquifers because, whether old or new water wells (those without casing leaks and those which may have them) are considered, and whether wells in the upper or the lower part of the Pleistocene section (below the purely surficial zones) are considered, the fact is readily apparent that fresh waters are chiefly obtained outside the 1,000-parts isosalinity line and nonpotable waters are chiefly obtained inside the 4,000-parts line. This fact is well known to the water-well drillers of the area, to real estate dealers, and to farmers.

ALTERNATIVE HYPOTHESES

The possible alternative explanations for the production of a regionally uniform gradient of chlorine which increases down the dip in a series of superimposed aquifers, center around the following concepts.

A. Entry of surface waters into the aquifers through the outcrop and dilution of their contained connate brines by flow and diffusion down the dip
B. An original fortuitous arrangement of connate waters, not essentially modified in their chlorine content by later changes
C. An original arrangement of connate waters controlled by pre-existing or concurrently produced basin structure

D. Seepage of marine brines into sediments previously more or less saturated with other types of waters
E. Down-dip chlorine gradients produced through the operation and interaction of such depth factors as temperature, pressure, compaction of strata, and the gravitative settling of waters of high specific gravity

It has already been stated that hypotheses B and C involve too great a degree of coincidence of events at widely separated times to seem of importance.

In hypothesis D, the seepage of marine brines into sediments after their deposition, there are two possible cases.

1. Entry of brine into eroded, submerged parts of an aquifer, case *g*, Table IV and Figure 7, *g*.

2. Downward penetration of brine into the sedimentary series through the caps of aquifers and the intervening strata in opposition to the increasing downward earth pressures.

It has already been argued that case *g* is a wholly hypothetical case and that it is not known to the writer that appreciable quantities of brine may gain entrance to aquifers in this manner. The downward penetration of brine into the earth for 800–1,200 feet and its outward and up-dip diffusion or flow for a score or more of miles seem highly improbable, if not impossible, under general conditions.

Possible hypotheses might be erected under the foregoing general heading E, by attempting theoretical reconstruction of underground physico-chemical environments during Pleistocene and Recent time and their evolutions. For example, Plummer has suggested[16] the possibility that water vapor may originate in aquifers at points of maximum pressures and move, while vaporized, to points of minimum pressures. Loss of water would raise the concentration of the dissolved salts, and addition of water through condensation would lower the concentrations.

Cheney[17] has suggested that underground waters, being controlled in their movements by differential pressures, should, according to theory, move up-dip in the sands, if compaction of strata forces water out of the clays into the sands, which furnish the avenue of least resistance. The great difference between the original high water content of silts and the final water content of clays and shales indicates a great loss of water underground. However, if the disappearance of the water occurs through up-dip flow, one should expect to find brine springs common at the outcrops of sands in most young sediments, unless the action is so slow that it is offset by down-dip

[16] F. B. Plummer, letter of October 25, 1934.

[17] M. G. Cheney, oral discussion, Laredo meeting, San Antonio Section, The American Association of Petroleum Geologists, November 2–5, 1934.

entry of fresh surface waters. This is a subject which invites study, since there are available in the Gulf Coast several outcrops which show brine springs; for example, the Jackson outcrop in East Texas and Louisiana. Brine is not uncommon along the outcrop of the Lissie northwest of Houston, along the Hockley Scarp. The Lissie outcrop in the sub-humid zone outside the area of shallow salt domes would be the best place to look for brine seepages caused solely by compaction of strata.

If fresh surface waters entered a non-saturated sand bed which contained somewhat equally distributed marine salts in the matrix of the sand grains, a gradual solution of these salts would occur as the waters moved down the dip, and a regular down-dip gradient from low to high salinity might conceivably be produced. This supposition would involve, however, the origin of the marine salts of the matrix and the loss of the water in which they were originally dissolved. It results, thus, that we are again dealing with case *a*, of Table IV and Figure 7, *a*.

In regard to the underground temperatures and pressures of the Pleistocene beds, it is evident that the present temperature range is probably of the order of 22° F., or between 70° and 92°, while the hydrostatic pressures in the aquifers between 200 and 1,200 feet underground range from 90 to 530 pounds per square inch.

Some additional effects of compaction might include a down-dip gradient of decreasing permeability which would gradually retard down-dip flow of fresh waters into brines, and it might also be that compaction is forcing deep waters upward across the strata so that the deeper parts of any dipping bed would have received more of these deep waters than the shallower parts would have received, at a given time. Since such ascending waters would become highly concentrated, the lower parts of dipping beds would contain more saline waters than the upper parts, especially if these were also receiving fresh waters through the outcrop.

If underground waters are forced upward across the strata by compaction, or if there is significant upward movement through the reservoir caps by water under molecular forces, the chemical reactions of base exchange would occur with the minerals of the clays. These reactions would change the types of the ascending waters, but would not alter the concentrations of the chlorine radical.

Until experiments shall have thrown more light upon these possibilities of the effect of depth factors upon chlorine concentrations in aquifers, and until there are more surveys of the chemical content of artesian aquifers, the working out of a satisfactory evolutionary

history of the changes of underground waters caused by these physico-chemical factors seems not to be practicable. In so far as they have been here reviewed, these factors seem not to oppose the hypothesis of the present paper, that isosalinity lines should run approximately parallel with structural contours.

The writer feels that, on the basis of the evidence and arguments presented in this study, the most plausible theory of origin of the observed down-dip increase of chlorine concentration in aquifers of the Woodbine of East Texas and of the Lissie and Beaumont of South Texas is that of the entry of fresh surface waters into the outcrop and their flow down the dip to mix with connate brines.

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RELATION OF GEOPHYSICS TO SALT-DOME STRUCTURES[1]

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ABSTRACT

This paper presents eighteen geophysical maps covering nine salt domes and deep-seated structures of the Texas and Louisiana Gulf Coast. Two shallow domes, namely, Moss Bluff and Fannett, are given. Fannett is a gravity maximum, and Moss Bluff is a combination of a gravity minimum and maximum. The Sugarland dome is given as an example of a medium-depth structure, which is indicated by the torsion balance as a minimum. Six deep-seated structures are shown, including Sheppards Mott, Pledger, Mykawa, Tomball, Livingston, and English Bayou-Gillis. The deeper-seated structures invariably show a gravity-minimum influence.

A refraction seismograph map of Moss Bluff is given, and reflection-seismograph maps are given for Sheppards Mott, Tomball, and English Bayou-Gillis. A magnetic map of the Fannett field is likewise presented.

INTRODUCTION

The primary object of this paper is to assemble and present a selective set of geophysical pictures found by investigating several types of Texas and Louisiana Gulf Coast salt-dome structures.

To the present time, the successful methods of geophysical exploration on the coast have been restricted to refraction and reflection seismograph and to the torsion balance and pendulum of the gravity instruments. In the search for commercial oil fields in the coast it is generally assumed that the associated structure has some relation to salt uplift or doming. Where the salt or cap rock is less than 3,000 feet deep, the dome is called shallow; where 3,000–5,000 feet, medium

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Without the generous coöperation and direct contribution of data by many companies and independent operators such a collection of maps could not have been made possible for publication. The writers take pleasure in acknowledging the contributions of the Gulf Production Company, the Humble Oil and Refining Company, the Magnolia Petroleum Company, the Standard Oil Company of Kansas, the Cockburn Oil Company of Houston, and the Independent Exploration Company (Rosaire and Kannenstine). With a few exceptions, individual credit for the various maps is not given.

The writers are especially grateful to Paul Weaver for long and patient assistance in preparing the data. They are also not unmindful of the helpful suggestions of George Sawtelle and Donald C. Barton, editors of the Gulf Coast salt-dome volume, which is to be published by The American Association of Petroleum Geologists, and of which this article is to be a part.

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depth; and below 5,000 feet, deep-seated, whether or not salt or cap rock has been found by drilling.

The geophysical maps presented herewith are prototypes of investigations covering the foregoing types of structures. They are presented as types rather than a definition of the particular structure covered. Thus, Fannett and Moss Bluff are given to illustrate gravity effects over shallow domes. Sugarland is given as a medium-depth dome. Sheppards Mott, Pledger, Mykawa, Tomball, Livingston, and English Bayou-Gillis are given as deep-seated domes or structures. One refraction map, three reflection seismograph maps, and one magnetometer map are presented, and the remaining are torsion-balance maps. No pendulum data are yet available for publication.

MOSS BLUFF DOME

Moss Bluff dome, in Chambers and Liberty counties, Texas, was discovered by the refraction seismograph in 1926. It is a shallow dome with the top of the cap rock at a depth of 650 feet and the top of the salt at 1,170 feet. Figure 1 shows the general relation of the wells drilled to date with regard to the dome. For ease of comparison with the geophysical figures, the 4,500-foot salt contour is represented on all the Moss Bluff figures.

The torsion-balance map of Moss Bluff (Fig. 2) is characterized by minimum gradients surrounding the dome and large positive maximum gradients over the cap rock. This is typical of all domes in which the pediment spreads rapidly with depth. The reëntrant in the 700-foot (drilling) contour causes a small minimum of an interesting nature.

The curvature quantities shown in Figure 3 record very little regional influence. They are directly radial to the edge of the salt about the 4,500-foot contour, excepting on the southeast flank, where the regional dips perhaps have influenced them to some extent.

A typical refraction seismograph picture of a shallow dome is shown by Figure 4. Salt leads of about ½ second are indicated in both the profile and line shots.

FANNETT DOME

The Fannett dome, in Jefferson County, Texas, was found by the seismograph in 1925 and, in contrast to the Moss Bluff dome, is a vertical-sided, narrow stock. The gradient picture, as shown by Figure 5, is, therefore, a decidedly typical maximum with no outside minimum effect. The curvatures shown in Figure 6 are the most orthodox occurring on any coastal dome, with the exception that the 90° break

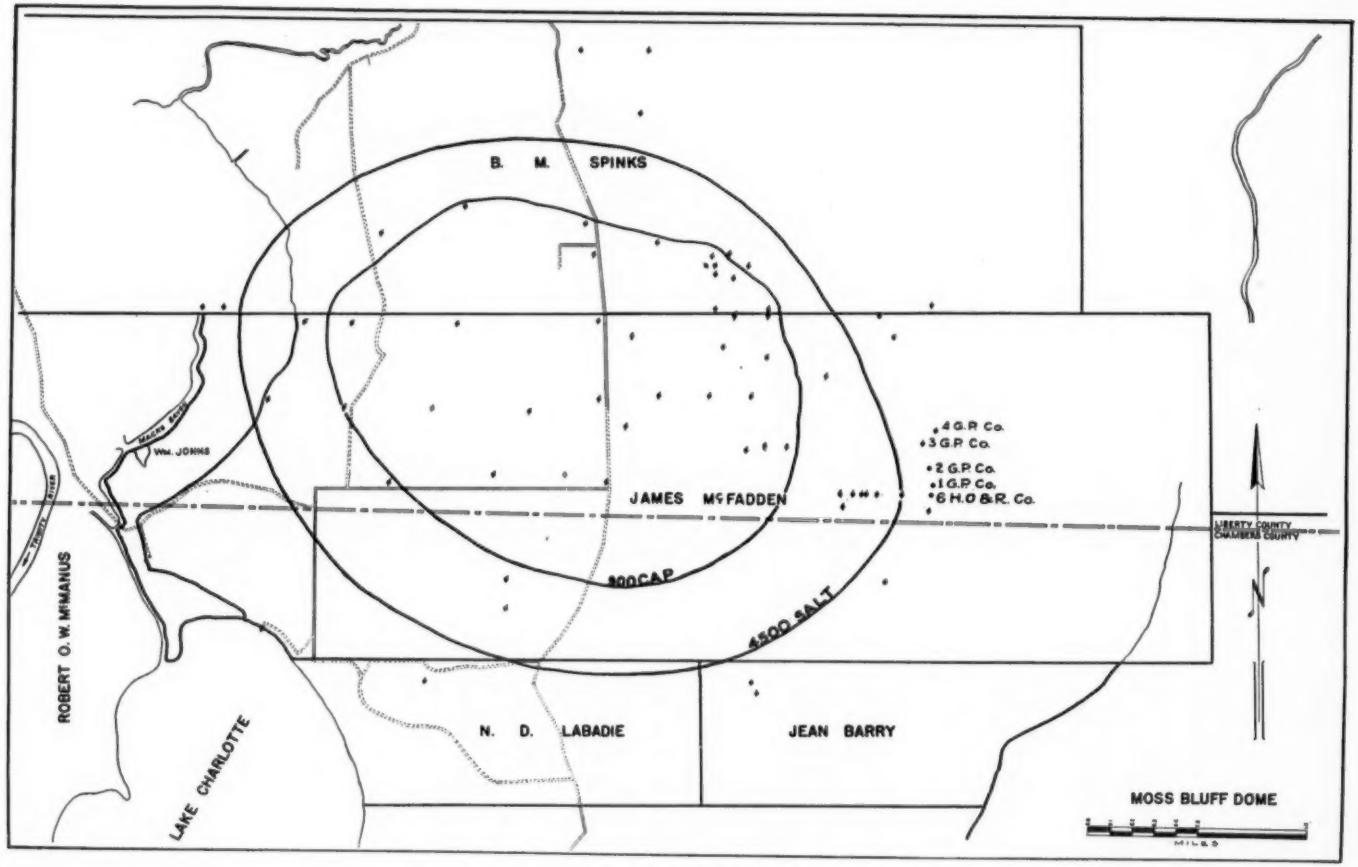

FIG. 1. Scale: $1\frac{1}{16}$ inches = 1 mile.

FIG. 1. Scale: $1\frac{5}{16}$ inches = 1 mile.

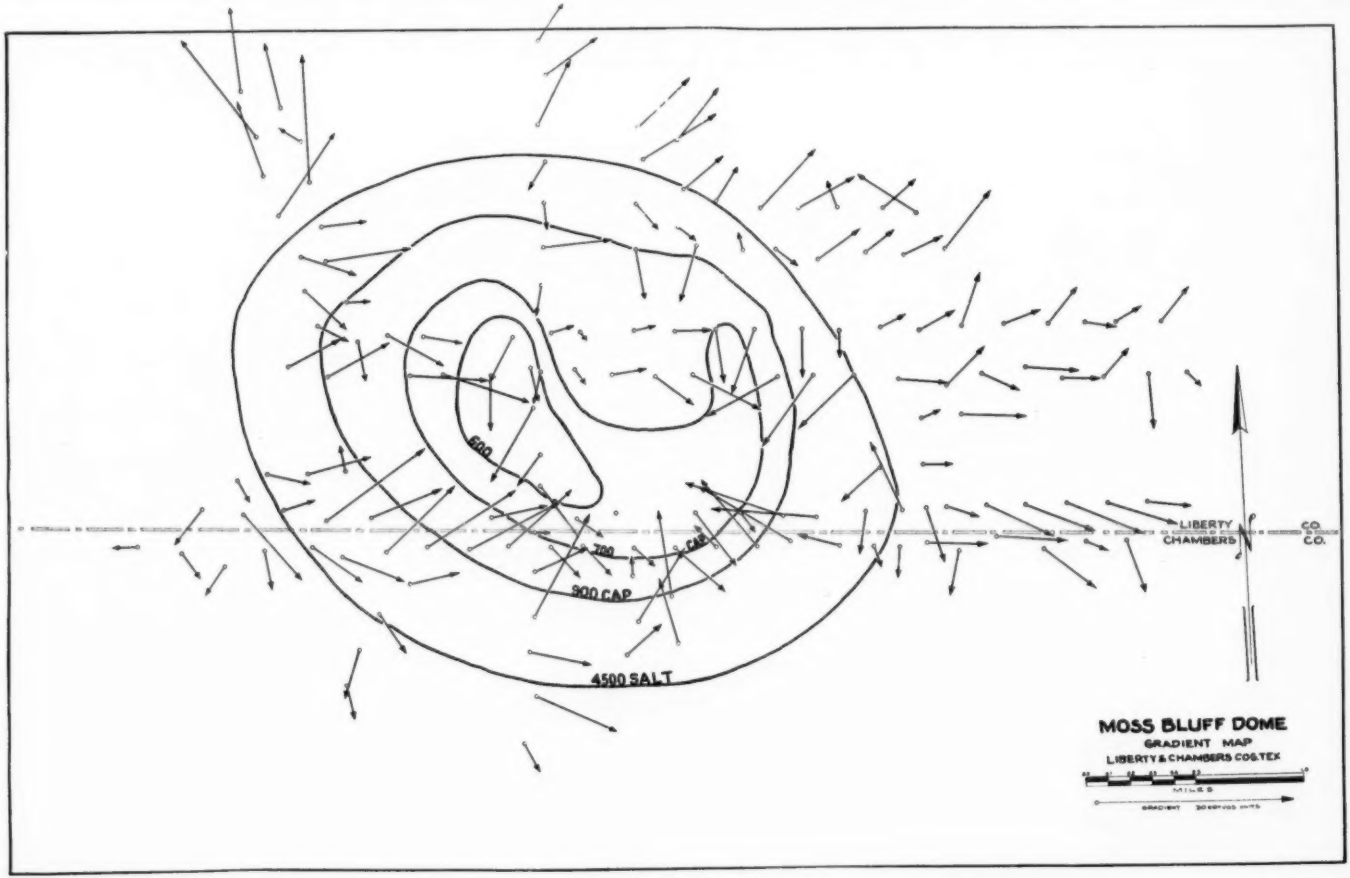

FIG. 2

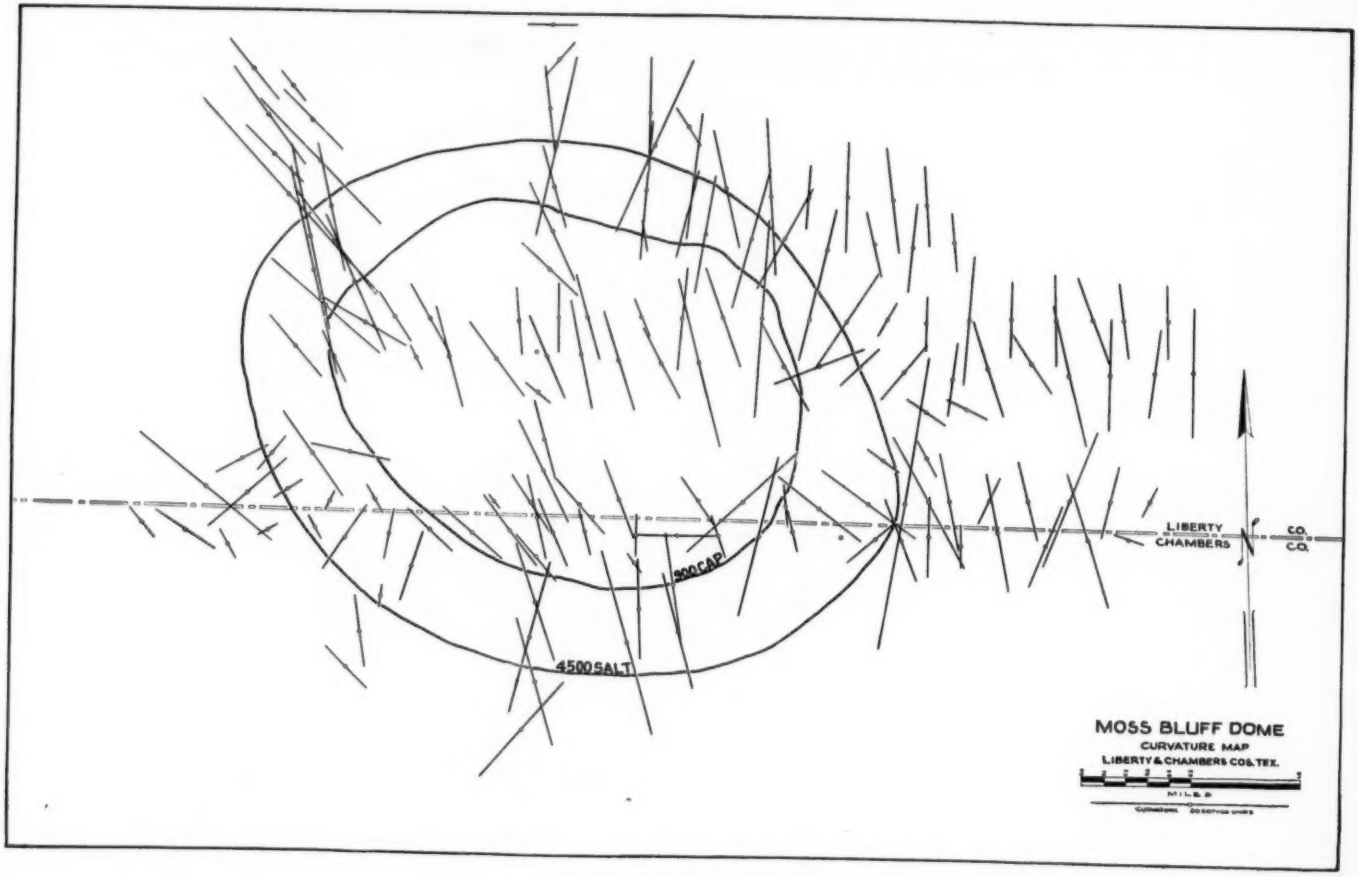
LIBERTY
CHAMBERS
CO.
CO.
900 CAP
4500 SALT
MOSS BLUFF DOME
CURVATURE MAP
LIBERTY & CHAMBERS COS. TEX.

FIG. 3

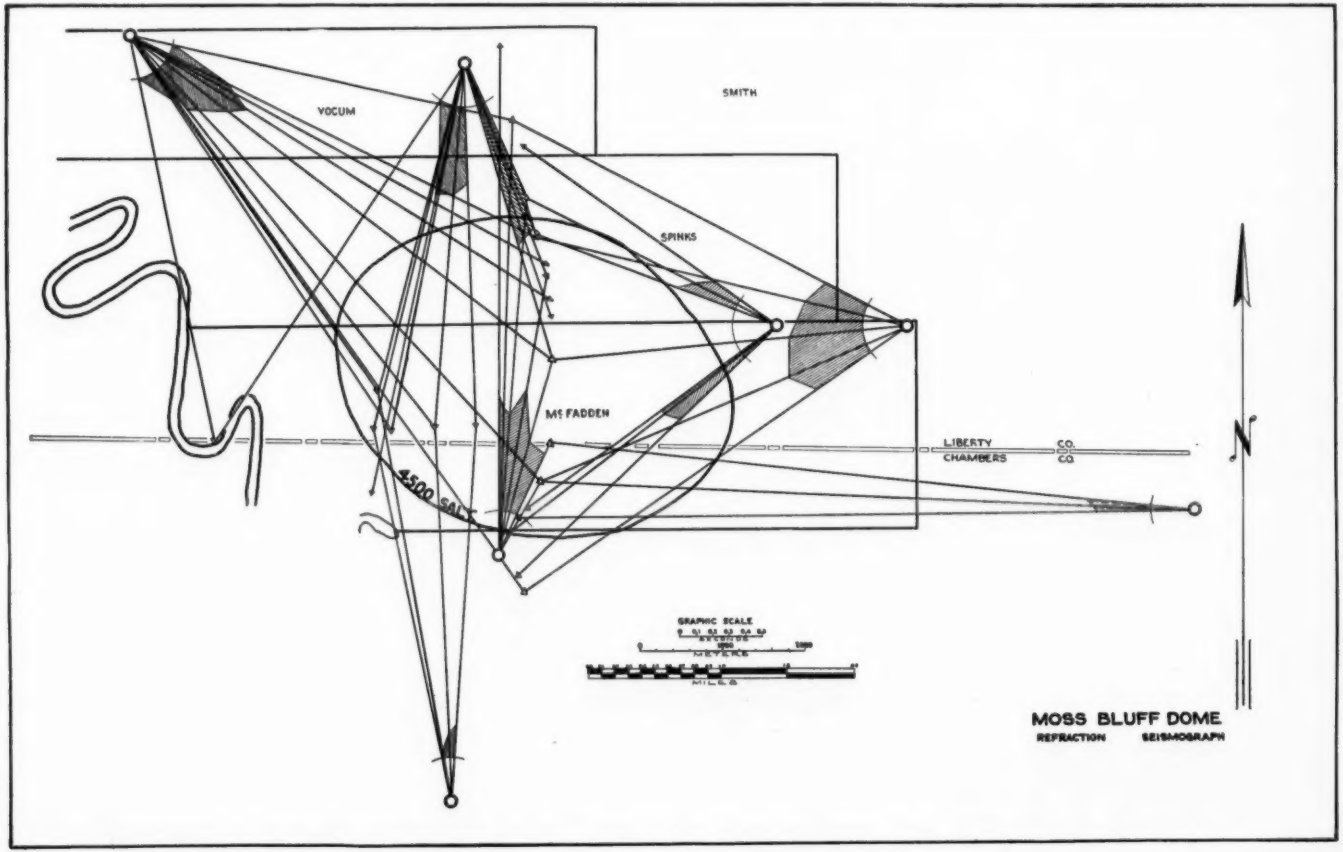
VOCUM
SMITH
SPINKS
Mc FADDEN
LIBERTY
CHAMBERS
CO.
CO.
4500 SALT
N
GRAPHIC SCALE
MOSS BLUFF DOME
REFRACTION SEISMOGRAPH

FIG. 4

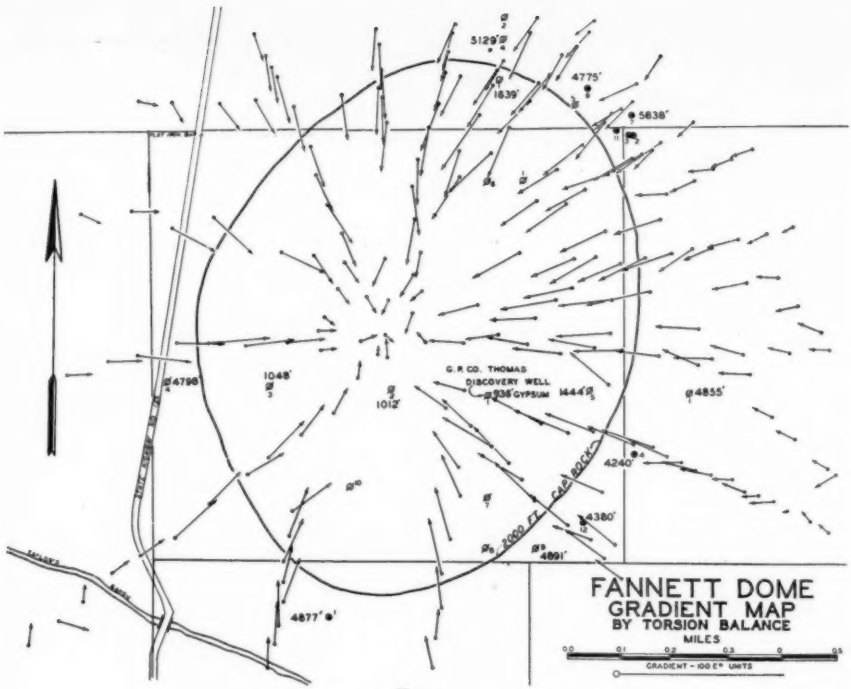
5129'
4775'
1639'
5838'
4798'
1048'
1012'
G.P.CO. THOMAS
DISCOVERY WELL
1444'
4855'
4240'
4380'
4891'
4877'
FANNETT DOME
GRADIENT MAP
BY TORSION BALANCE
MILES
GRADIENT - 100 E° UNITS

FIG. 5

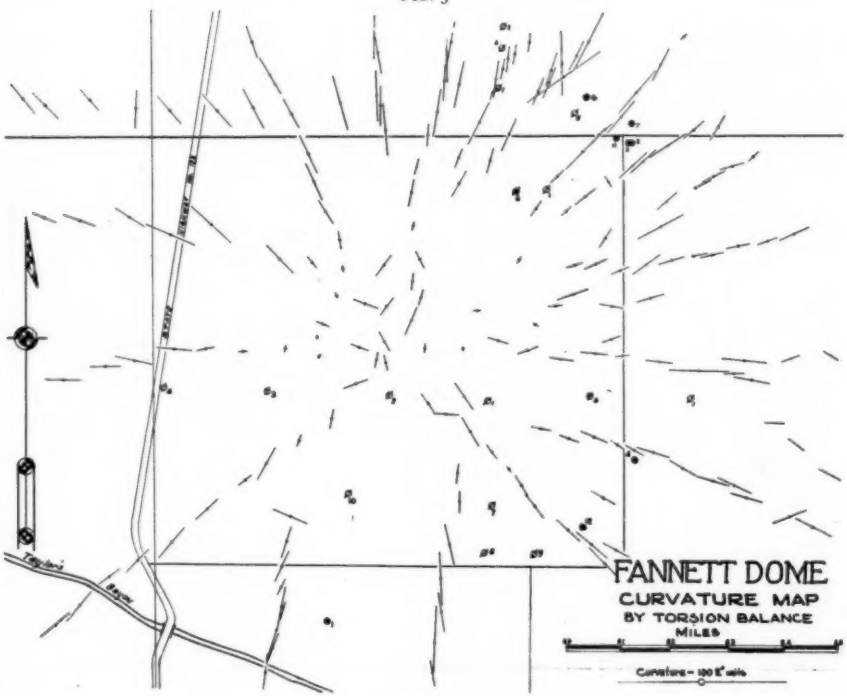
FANNETT DOME
CURVATURE MAP
BY TORSION BALANCE
MILES
Curvature - 100 E° units

FIG. 6

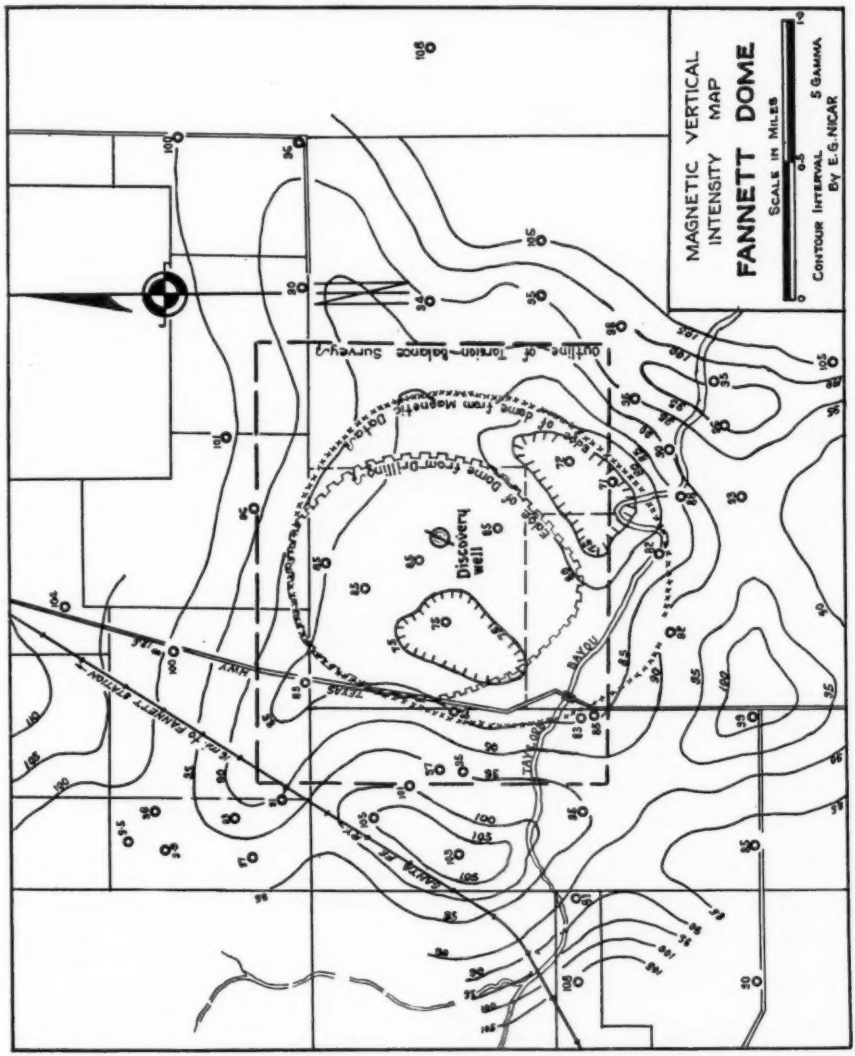
MAGNETIC VERTICAL INTENSITY MAP
FANNETT DOME
SCALE IN MILES
CONTOUR INTERVAL 5 GAMMA
By E.G. NICAR
Outline of Torsion-balance Survey
Outline of dome from Magnetic data
Outline of dome from Drilling
Discovery well
TEXAS
HWY
TAYLOR BAYOU
To FANNETT STATION

FIG. 7

in direction occurring at the edge of the cap rock is in some cases reflected only by rapid shortening of the length of the *R* line rather than a directional change.

The magnetometer picture (Fig. 7) is given more for its scientific interest than for its practical value. The vertical intensity shows a 5-gamma closure which, in the opinion of the writers, is not sufficient for commending its use for new dome discoveries.

SUGARLAND DOME

The Sugarland dome, Fort Bend County, Texas, was discovered more or less jointly by the torsion balance and the seismograph in 1927 and 1928. It developed into one of the most prolific oil-producing structures in the Gulf Coast (Fig. 8).

The gradient map (Fig. 9) shows a well defined minimum for the structure at large. A small cap-rock area near the center of the dome (compare Figures 8 and 9) shows definite maximum effect.

The curvature map of Sugarland (Fig. 10) shows a distinct regional effect, the values on the east and west sides of the dome being of an order of twice that of those on the north and south, where the regional effect has been overcome by the salt.

SHEPPARDS MOTT DOME

Sheppards Mott dome, in Matagorda County, Texas, was discovered by the torsion balance for the Cockburn Oil Company and the gradient and reflection seismograph maps shown herewith are given by courtesy of H. C. Cockburn, of Houston, Texas. Since salt has not been encountered yet in wells drilled deeper than 6,000 feet, the dome is classified as a deep-seated structure.

The gravity map (Fig. 11) shows a northward sweep of considerable magnitude and a distinct fanning of the gradients in the McCarthy and Frye Surveys. Because of an enormous regional effect, it appears difficult to obtain adequate "southing" (gradients pointing south). The gradients in the center of the picture are small and confused, suggesting that the arching of the strata over the salt has caused a small amount of maximum influence to impress itself into the picture.

It is further interesting to note that the wells more than 6,000 feet deep in the center of the picture failed to find salt, yet the gradients of gravity are much larger than those found on Sugarland with a salt depth of more than 4,000 feet (Fig. 9).

The reflection map of Sheppards Mott (Fig. 12) shows about 1,400 feet of closure, with the highest closing contour at an approximate depth of 5,000 feet.

PLEDGER FIELD

The Pledger structure, in Brazoria County, Texas, was first determined by reflection shooting. The torsion-balance picture (Fig. 13) was made by W. C. Neville, of Houston, Texas, and is published with his permission. It was made prior to the reflection shooting.

So strong is the southwest regional influence that the minimum effect can be detected only in a few scattered reversals occurring about midway in each line of gradients. A feature of the picture is the maximum occurring around the discovery well.

MYKAWA

The Mykawa structure, in Harris County, Texas, is generally considered a torsion-balance discovery (Fig. 14). The producing oil field seems to occur on the northwest extension of a much larger gravity-minimum axis extending south and southeast. The junior writer believes that the strong north gradients in the John Randon Survey and the distinct east gradients in the Robert Cameron Survey suggest that the structure has not yet been adequately explored by the drill to determine its true character and extent.

TOMBALL FIELD

The Tomball field, in northern Harris County, Texas, is another geophysically discovered field, with initial credit to the torsion balance. Figure 15 gives the gradient picture of this structure. In common with other structures of the Conroe trend, the Tomball picture is characterized by weak closure along the strike, namely, northeast and southwest. There is excellent gravitation closure both with and against the regional dip.

The reflection picture of Tomball is shown in Figure 16 and is the result of an investigation by the Independent Exploration Company prior to the development of the oil field. It will be seen that reflections have served notably well in delineating this structure.

LIVINGSTON FIELD

The Livingston field, Polk County, Texas, was discovered chiefly by torsion-balance indications of a minimum. The gravitational picture of this prospect (Fig. 17) shows it to be a subsidiary minimum attached to the north flank of a regional minimum. The curvature lines in the vicinity of the discovery wells would tend to postulate a peripheral fault. It is especially interesting to note that a producing field has been found on such scanty evidence and lends increasing importance to similar gravity anomalies on the coast that are yet unexplored.

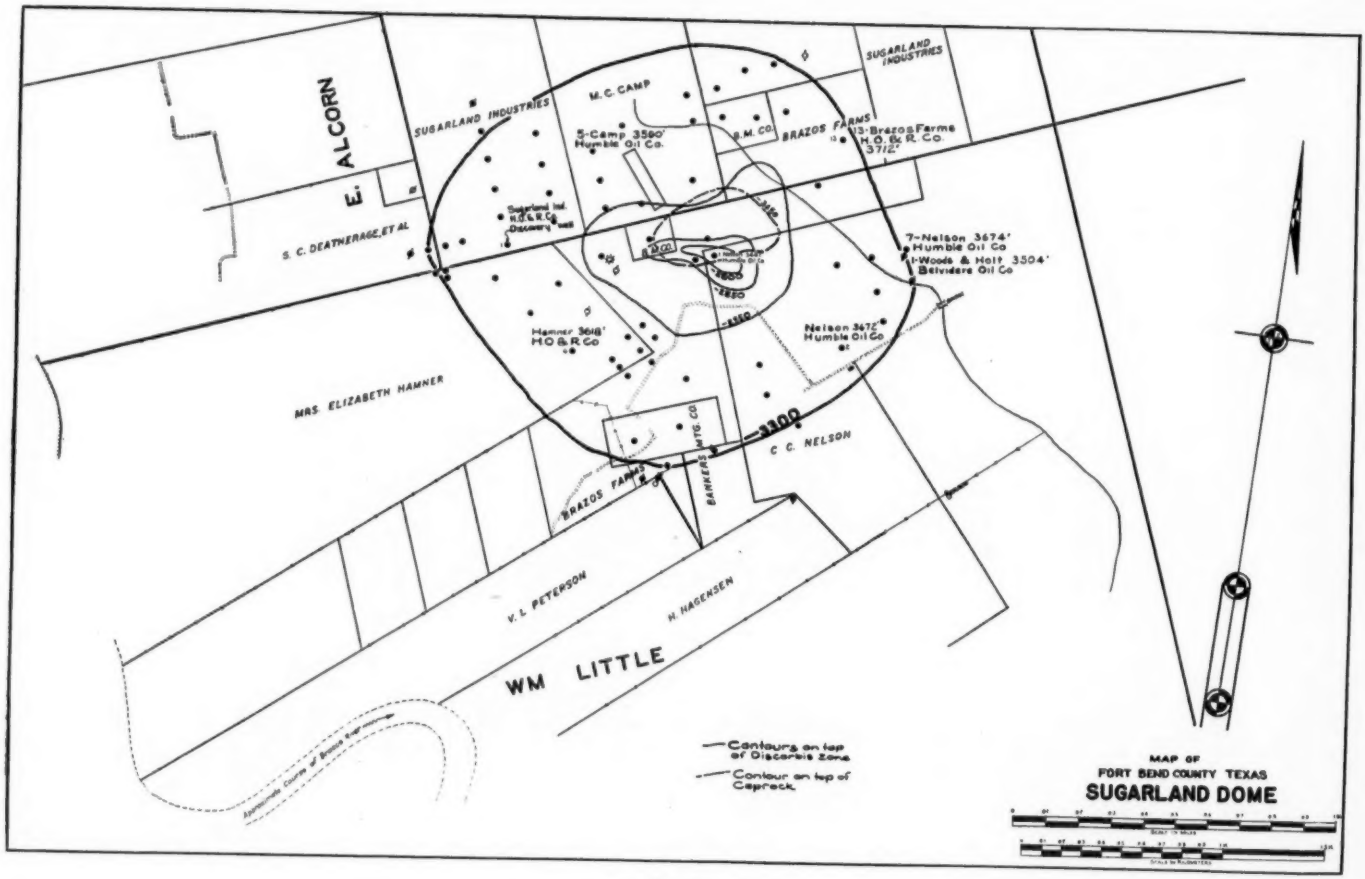
E. ALCORN
SUGARLAND INDUSTRIES
M.C. CAMP
5-Camp 3590'
Humble Oil Co.
G.M. CO.
BRAZOS FARMS
13-Brazos Farms
H.O. & R. Co.
3712'
SUGARLAND INDUSTRIES
S. C. DEATHERAGE, ET AL
Sugarland Ind.
H.O.&R.Co.
Discovery
7-Nelson 3674'
Humble Oil Co
1-Woods & Holt 3504'
Belvidere Oil Co
3200
3250
3300
Hamner 3618'
H.O.&R.Co
Nelson 3672'
Humble Oil Co
MRS. ELIZABETH HAMNER
BARKER MTG. CO.
C. C. NELSON
BRAZOS FARMS
V. L. PETERSON
H. HAGENSEN
WM LITTLE
Contours on top of Discorbis Zone
Contour on top of Caprock
MAP OF
FORT BEND COUNTY TEXAS
SUGARLAND DOME

FIG. 8

FIG. 8

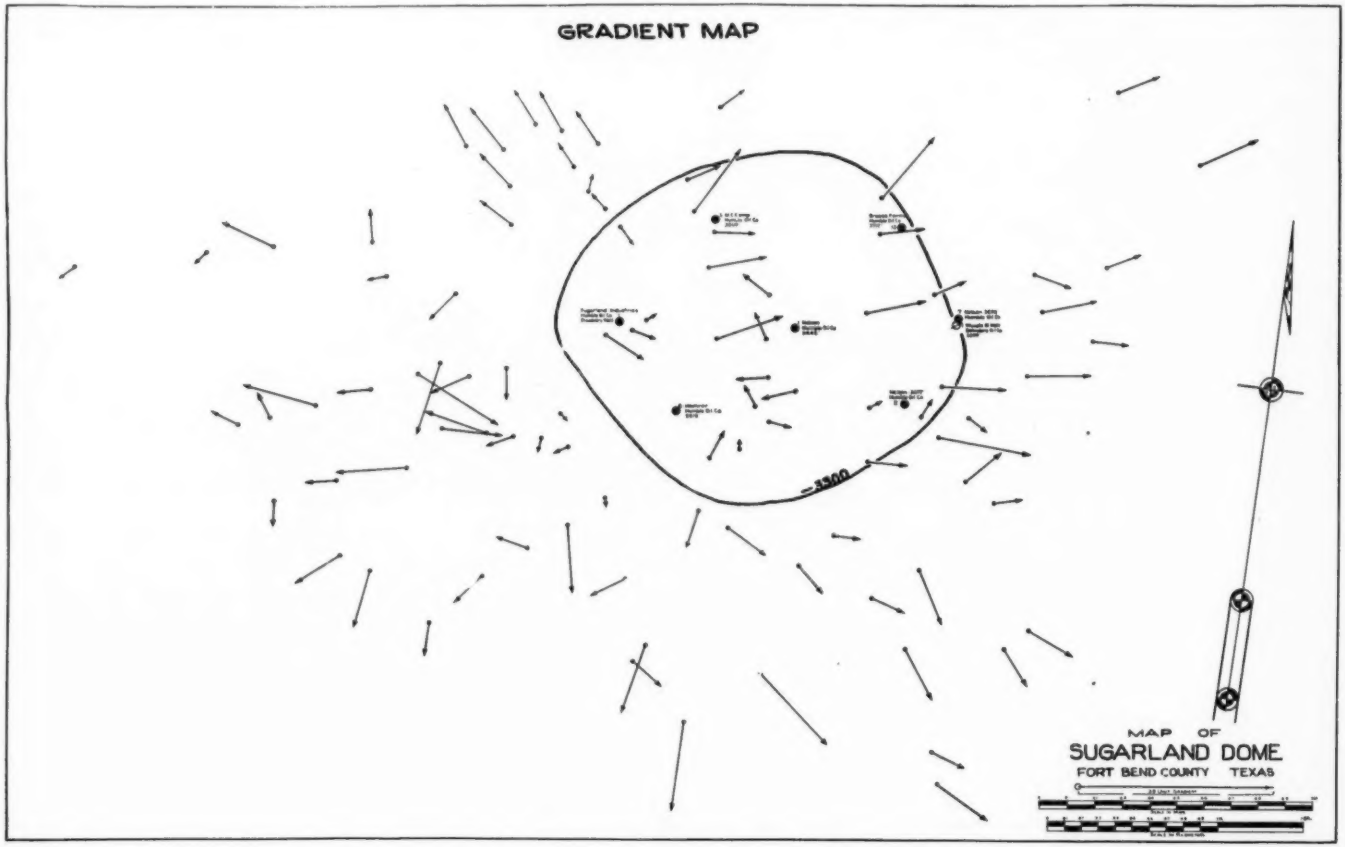
GRADIENT MAP
-3300
MAP OF
SUGARLAND DOME
FORT BEND COUNTY TEXAS

FIG. 9

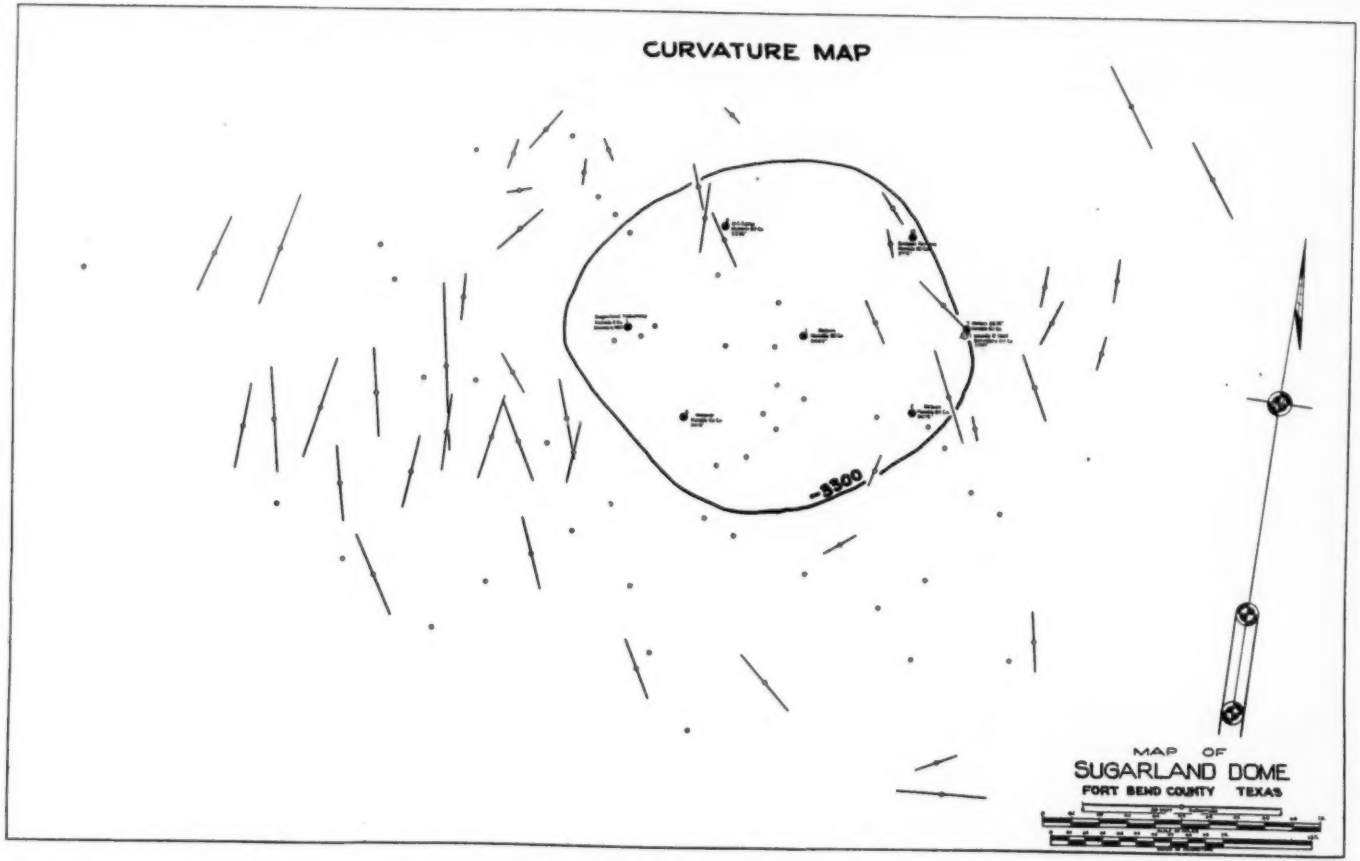
CURVATURE MAP
-3500
MAP OF
SUGARLAND DOME
FORT BEND COUNTY TEXAS

FIG. 10

FIG. 10

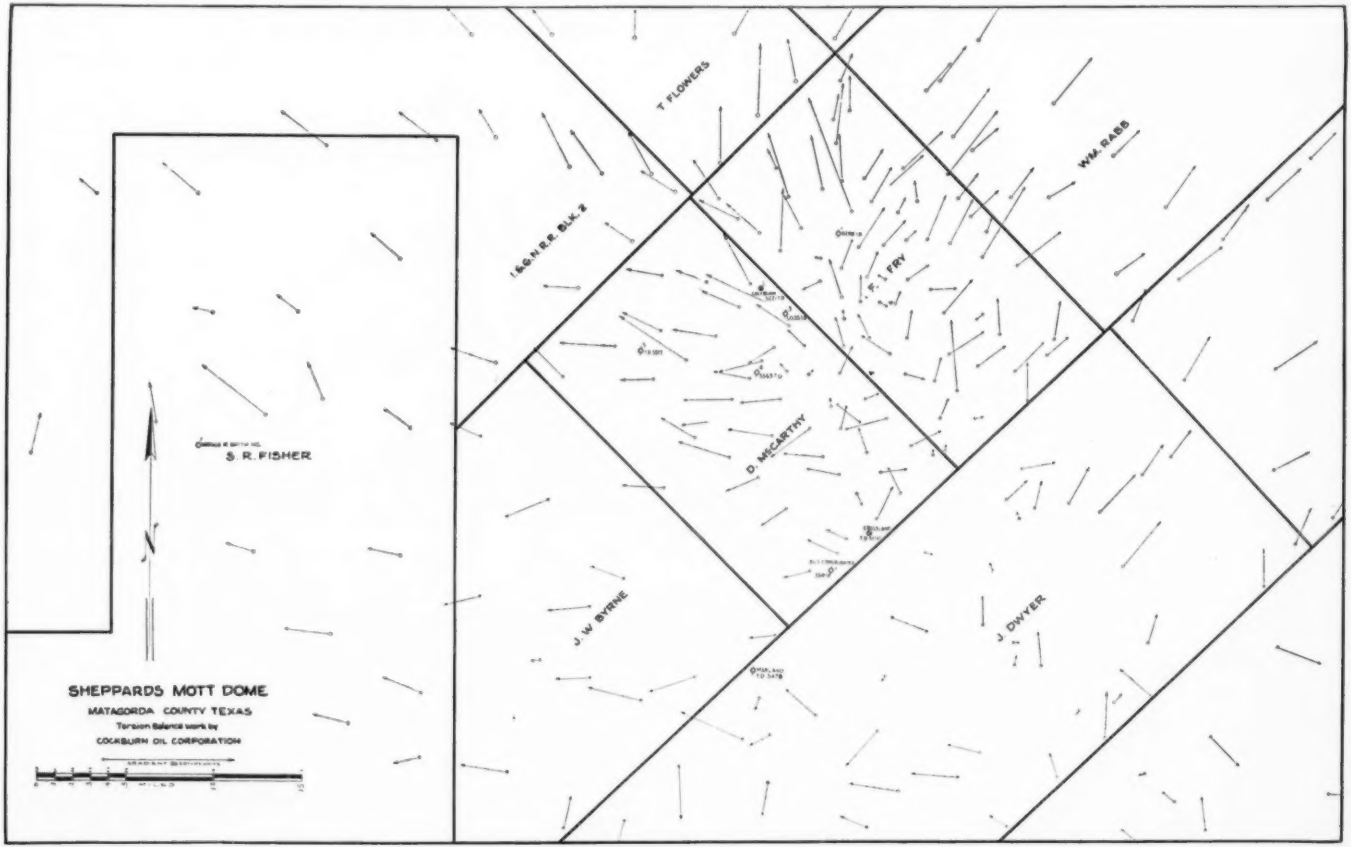
T. FLOWERS
I. & G. N. R.R. BLK. 2
WM. RABB
F. I. FRY
D. McCARTHY
J. W. BYRNE
J. DWYER
S. R. FISHER
SHEPPARDS MOTT DOME
MATAGORDA COUNTY TEXAS
Torsion Balance work by
COCKBURN OIL CORPORATION

FIG. 11

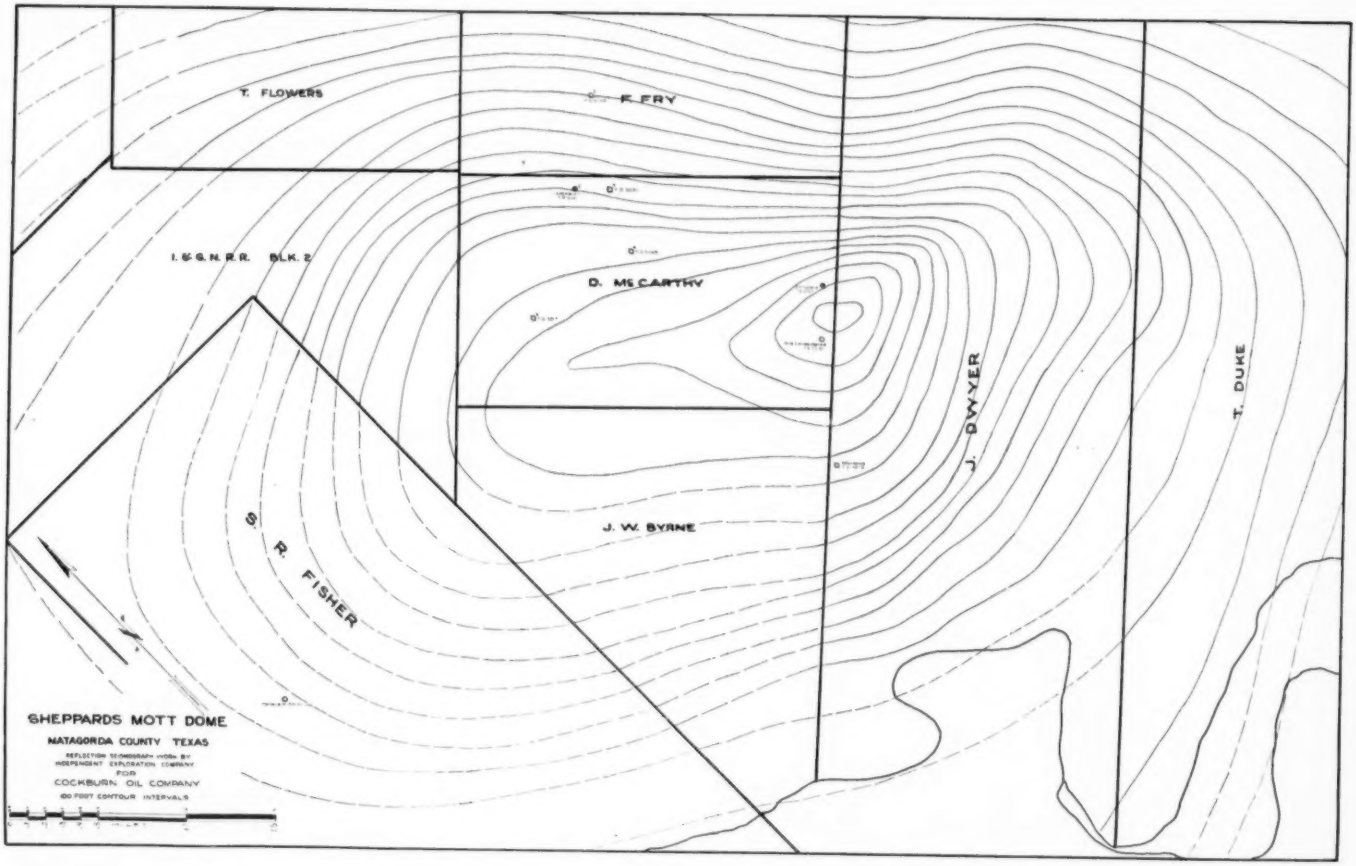
T. FLOWERS
F. FRY
I. & G. N. R. R. BLK. 2
D. McCARTHY
J. DWYER
T. DUKE
J. W. BYRNE
S. R. FISHER
SHEPPARDS MOTT DOME
MATAGORDA COUNTY TEXAS
REFLECTION SEISMOGRAPH WORK BY
INDEPENDENT EXPLORATION COMPANY
FOR
COCKBURN OIL COMPANY
100 FOOT CONTOUR INTERVALS

FIG. 12

FIG. 12

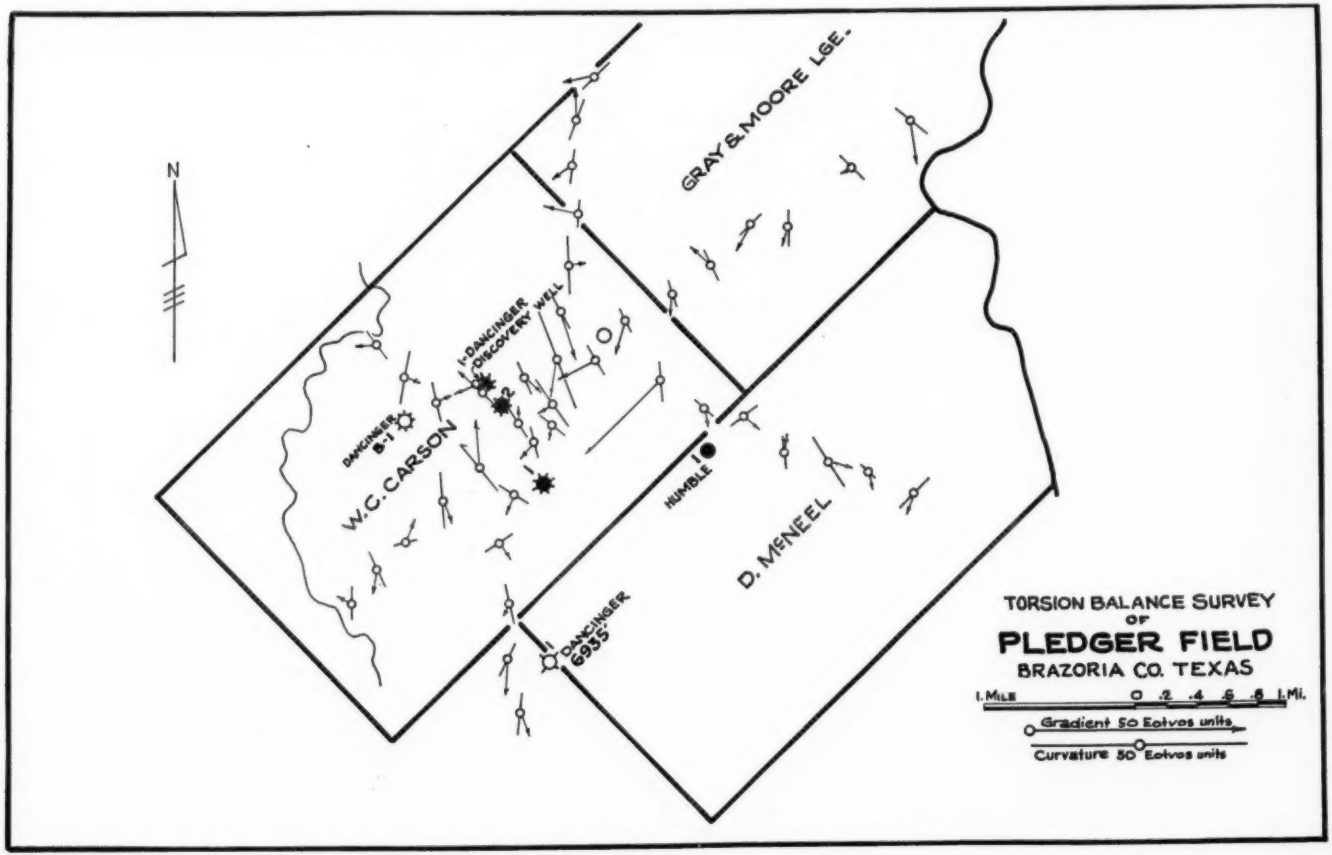
N
GRAY & MOORE LGE.
DANCINGER DISCOVERY WELL
DANCINGER B-1
W.C. CARSON
HUMBLE
D. McNEEL
DANCINGER 6935
TORSION BALANCE SURVEY
OF
PLEDGER FIELD
BRAZORIA CO. TEXAS
1 MILE
0 .2 .4 .6 .8 1 MI.
Gradient 50 Eotvos units
Curvature 50 Eotvos units

FIG. 13

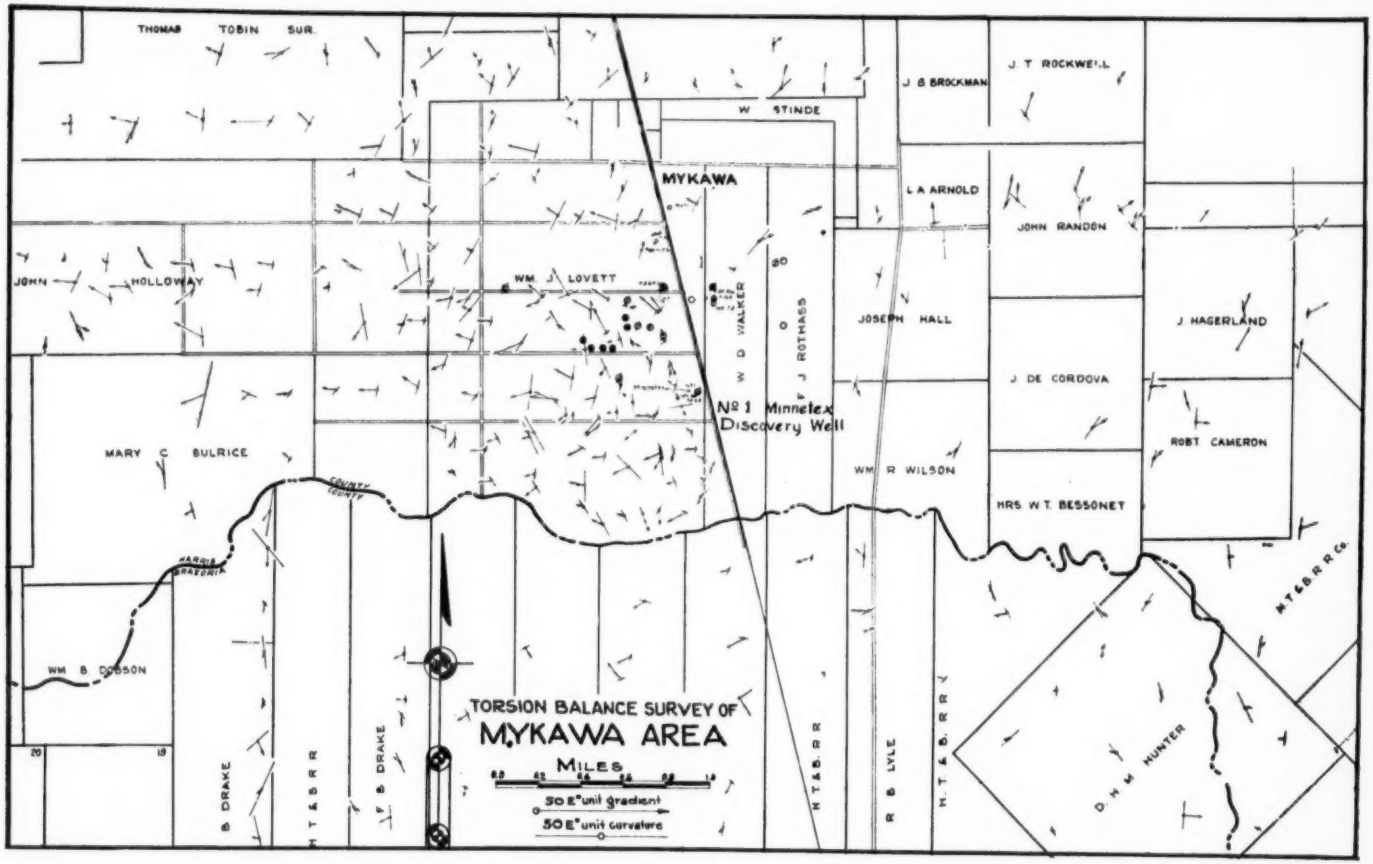
THOMAS TOBIN SUR.
J. B. BROCKMAN
J. T. ROCKWELL
W. STINDE
MYKAWA
L. A. ARNOLD
JOHN RANDON
JOHN HOLLOWAY
WM. J. LOVETT
W. D. WALKER
F. J. ROTHASS
JOSEPH HALL
J. HAGERLAND
J. DE CORDOVA
No 1 Minnelex Discovery Well
MARY C. BULRICE
WM. R. WILSON
ROBT. CAMERON
MRS. W. T. BESSONET
HARRIS GRATORIA
WM. B. DOSSON
B. DRAKE
H. T. & B. R. R.
F. B. DRAKE
R. B. LYLE
H. T. & B. R. R.
M. T. & B. R. R. Co.
D. H. M. HUNTER
TORSION BALANCE SURVEY OF
MYKAWA AREA
MILES
50 E. unit gradient
50 E. unit curvature

FIG. 14

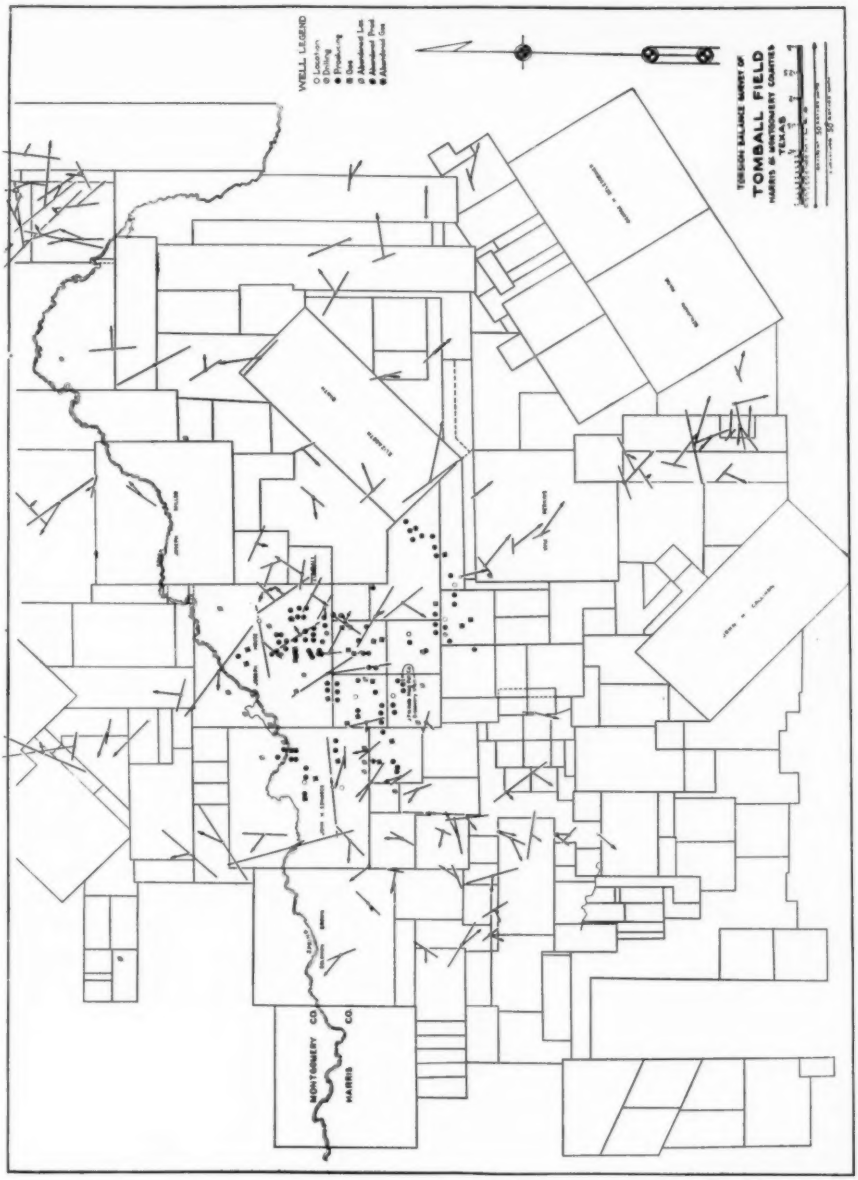
WELL LEGEND
TORSION BALANCE SURVEY OF
TOMBALL FIELD
HARRIS & MONTGOMERY COUNTIES
TEXAS
MONTGOMERY CO.
HARRIS CO.

FIG. 15

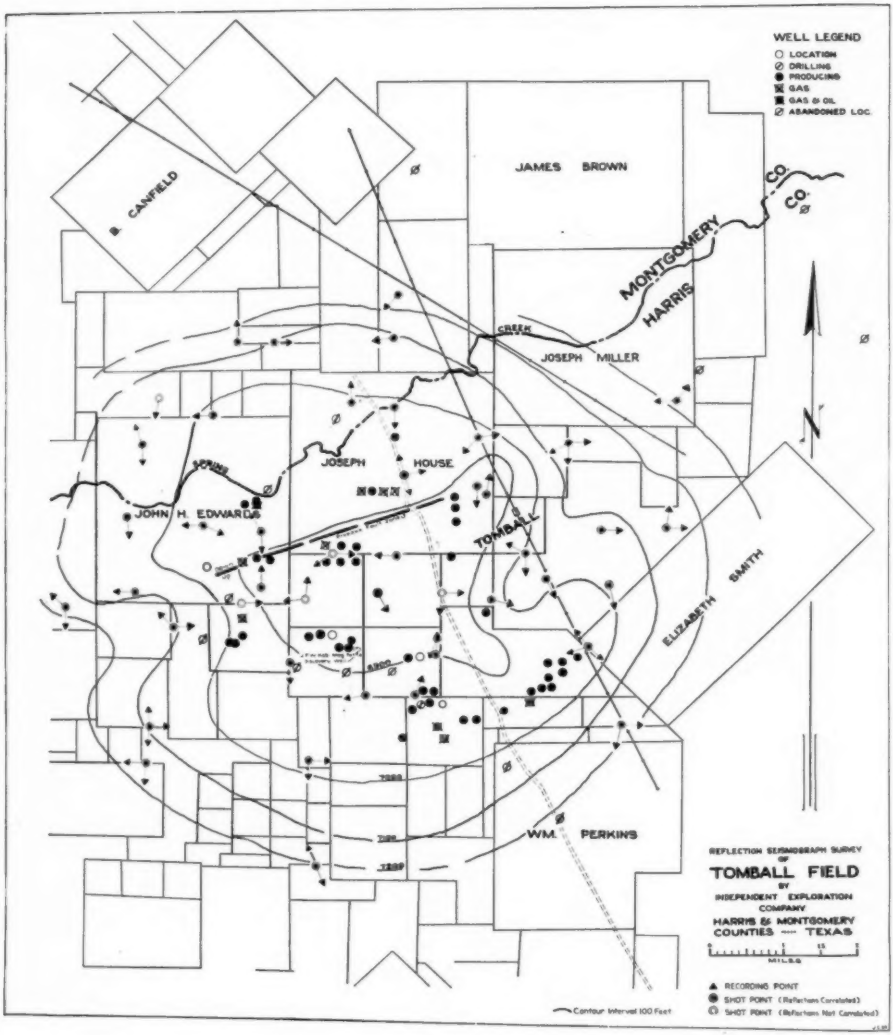
WELL LEGEND
LOCATION
DRILLING
PRODUCING
GAS
GAS & OIL
ABANDONED LOC.
CANFIELD
JAMES BROWN
MONTGOMERY CO.
HARRIS CO.
CREEK
JOSEPH MILLER
JOSEPH HOUSE
JOHN H. EDWARDS
TOMBALL
ELIZABETH SMITH
WM. PERKINS
REFLECTION SEISMOGRAPH SURVEY OF
TOMBALL FIELD
BY
INDEPENDENT EXPLORATION COMPANY
HARRIS & MONTGOMERY COUNTIES ---- TEXAS
MILES
RECORDING POINT
SHOT POINT (Reflections Correlated)
SHOT POINT (Reflections Not Correlated)
Contour Interval 100 Feet

FIG. 16

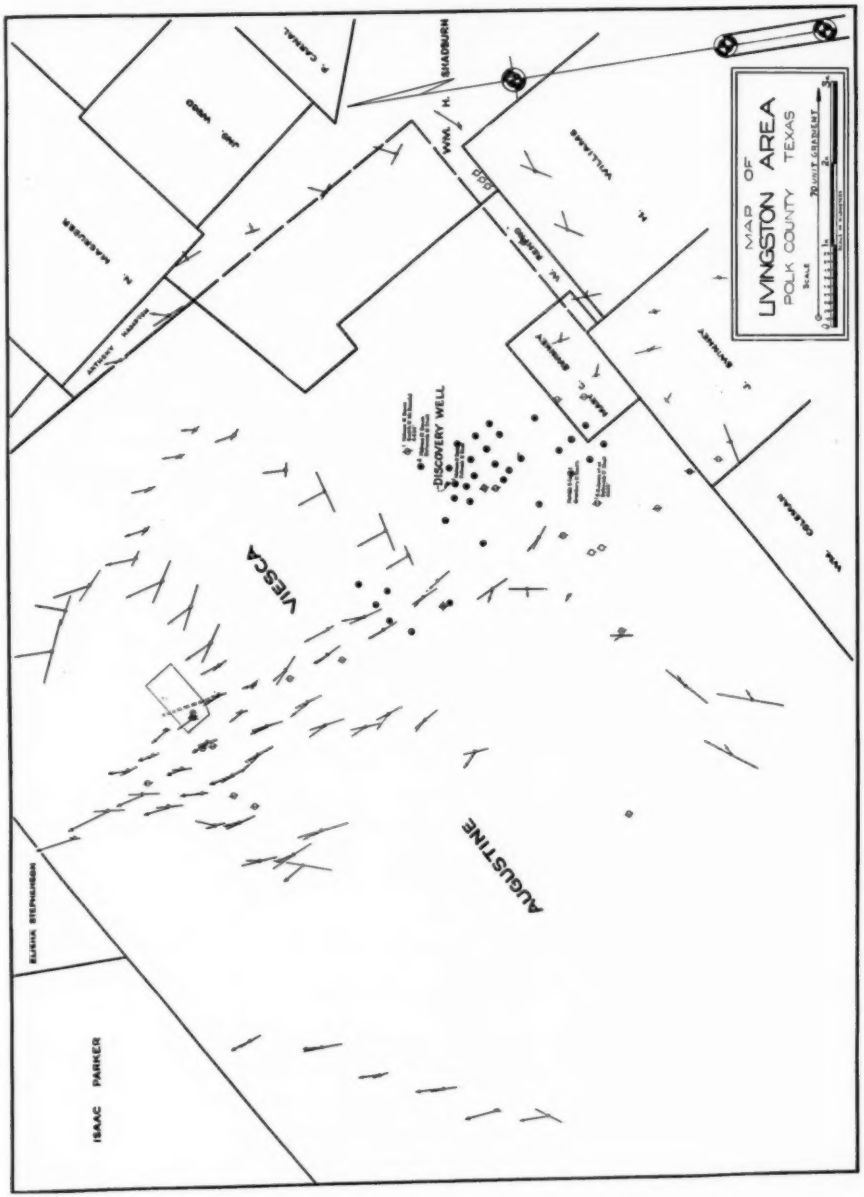
MAP OF
LIVINGSTON AREA
POLK COUNTY TEXAS
DISCOVERY WELL
VIESCA
AUGUSTINE
ISAAC PARKER
SHADBURN
WILLIAMS
ARMSTRONG
HARRISON
ANTHONY HAMPTON
EUREKA STEPHENSON

FIG. 17

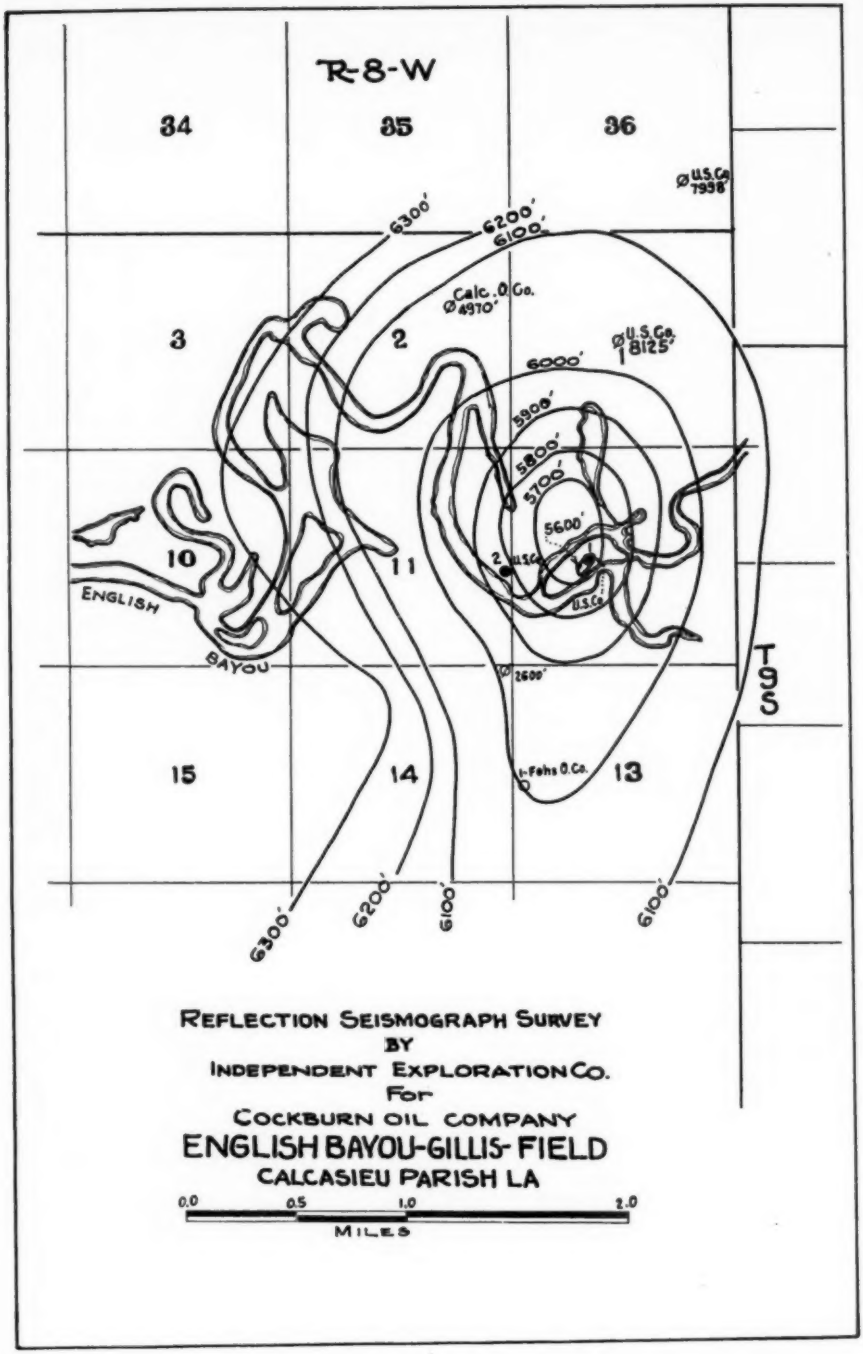
R-8-W
34
35
36
T 9 S
3
2
10
11
15
14
13
ENGLISH
BAYOU
6300'
6200'
6100'
6000'
5900'
5800'
5700'
5600'
Calc. O. Co.
Ø 4970'
Ø U.S.Co.
1 8125'
Ø U.S.Co.
7938'
U.S.Co.
2600'
1-Fehs O.Co.
REFLECTION SEISMOGRAPH SURVEY
BY
INDEPENDENT EXPLORATION CO.
For
COCKBURN OIL COMPANY
ENGLISH BAYOU-GILLIS FIELD
CALCASIEU PARISH LA
0.0
0.5
1.0
2.0
MILES

FIG. 18

ENGLISH BAYOU-GILLIS

The recent discovery of commercial oil on the English Bayou-Gillis structure, in Calcasieu Parish, Louisiana, near Lake Charles, is of especial interest to seismologists in that they contributed largely to its successful exploitation. The reflection map presented with this paper (Fig. 18) was made by the Independent Exploration Company for the Cockburn Oil Company, of Houston, and is published with the permission of H. C. Cockburn. The field work for this investigation was done prior to the drilling of any of the exploratory wells on this structure.

CONCLUSION

In concluding, the writers wish to point out again that it is their intention to present types rather than specific cases. It is hoped that the relation between the various branches of geophysics and the various kinds of coastal structures can better be appreciated by presenting these maps for actual reference. If this has been accomplished, the purpose of this paper is served.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 19, NO. 3 (MARCH, 1935), PP. 378-400, 4 FIGS.

BUCKEYE FIELD, MATAGORDA COUNTY, TEXAS[1]

E. W. BRUCKS[2]
San Antonio, Texas

ABSTRACT

The Buckeye field is on a very deep-seated domal uplift; it covers about 800 acres, according to the surface indications and a magnetometer survey. The first well drilled came in as a producer, August 31, 1932. Seven wells have been completed, and of these, two were commercial producers. The wells on a west-east cross section indicate that the uplift may cover less than 800 acres. A study of the subsurface reveals that the Upper Catahoula is undoubtedly of Miocene age. The oil horizon occurs in the upper part of the Lower Catahoula (Frio), at the depth of approximately 7,800 feet. This was the deepest commercial oil production in the Texas Gulf Coast at the time of its discovery. The field produced 362,397 barrels before the wells stopped flowing, and is still producing small quantities of oil on the pump. The field has been subdivided into 20-acre units.

INTRODUCTION

The purpose of the writer is to describe the structural feature and the stratigraphical relations of the Buckeye dome and to present other information closely related thereto. This prospect has produced some oil from the depth of 7,800–7,900 feet. There was no record of deeper production in the Texas Gulf Coast at the time of this discovery, August 31, 1932.

LOCATION

This area is located in the central part of Matagorda County, Texas, on the west side of Colorado River, about 15 miles upstream from the mouth of this river. It is named after Buckeye, a station on the Missouri-Pacific or St. Louis, Brownsville, and Mexico Railroad; it occupies the southern part of the J. C. Keller and the northern part of the G.B.M. Cotton leagues. Bay City, the county seat, is about 8 miles northeast, the town of Markham about 4 miles north-northwest, and Houston about 75 miles northeast. With respect to near-by producing salt domes, Buckeye is 10 miles southeast of the Markham

[1] Presented before the San Antonio Geological Society, July 2, 1934. Manuscript received, January 2, 1935. The United North and South Development Company of San Antonio, Texas, which has undertaken to develop this prospect, gave permission for the publication of this paper. The writer is indebted to B. M. Haberer, the company's engineer, for valuable assistance in the preparation of the maps and illustrations. To Miss Hedwig T. Kniker he is indebted for assistance in the paleontologic and stratigraphic determinations of the subsurface section. To Edgar W. Owen, he is indebted for helpful suggestions as to nomenclature usage.

[2] 354 Cavalier Avenue.

(Clemville) oil field, 15 miles northwest of the Gulf sulphur field, and 31 miles southwest of the West Columbia oil field.

HISTORY OF DEVELOPMENT

The Stoddard ranch, comprising about 10,000 acres, was submitted by its owners, early in 1931, for consideration as an oil and gas prospect, to the United North and South Development Company. During March of that year, the writer made a geological examination of this ranch, and selected the area surrounding the Buckeye townsite as showing stronger evidences of structure than any other part of this ranch.

The leasing of the area was started immediately after the writer's report was completed. Other companies, such as the Marland Oil Company, through Alexander Deussen, and the Humble Oil and Refining Company, were reported to have negotiated with the landowners for a lease contract in the past.

During September, 1931, F. E. Heatley was employed to make a magnetometer survey of this ranch.

On October 11, 1931, the first well on this prospect was spudded in. The intention originally was to drill it to the depth of 4,500 feet unless oil were discovered at lesser depth, to satisfy the lease contract on the Stoddard ranch. As shown in the type section (Fig. 2), several indications of uplift were revealed before this depth was reached. The Beaumont-Lissie of the Pleistocene was thinner by 90 feet than normally expected. The Lagarto member of the Pliocene was thinner by 300 feet than normal; and the Oakville, or Middle Fleming, of the Miocene showed a thinning of approximately 200 feet. These evidences of thinning are based on comparisons with another wildcat well in this region along the same strike.[3]

Since no oil or gas showing had been encountered, the drilling was continued. At the depth of 5,370 feet in an upper sand member of the Basal Fleming, a gas showing and an oil stain were encountered. But this showing was not of commercial value. Similarly, at the depth of 5,696 feet, a slight showing of oil and gas was found. The only showing of importance was found in the Lower Catahoula (Frio) formation at the depth of 7,765 feet, about 59 feet below the top of this formation. After repeated failures to bring in the well from a depth of 7,830 feet, the well was side-tracked and drilled to 7,951 feet. The sands between the depth of 7,765 and 7,926 feet showed oil and gas, but the section between 7,926 and 7,951 feet showed water. These water-bearing sands were plugged back. The sands of this pay sec-

[3] See footnote 5.

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VOL. 19, NO. 3 (MARCH, 1935), PP. 378-400, 4 FIGS.

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LOCATION

This area is located in the central part of Matagorda County, Texas, on the west side of Colorado River, about 15 miles upstream from the mouth of this river. It is named after Buckeye, a station on the Missouri-Pacific or St. Louis, Brownsville, and Mexico Railroad; it occupies the southern part of the J. C. Keller and the northern part of the G.B.M. Cotton leagues. Bay City, the county seat, is about 8 miles northeast, the town of Markham about 4 miles north-northwest, and Houston about 75 miles northeast. With respect to near-by producing salt domes, Buckeye is 10 miles southeast of the Markham

[1] Presented before the San Antonio Geological Society, July 2, 1934. Manuscript received, January 2, 1935. The United North and South Development Company of San Antonio, Texas, which has undertaken to develop this prospect, gave permission for the publication of this paper. The writer is indebted to B. M. Haberer, the company's engineer, for valuable assistance in the preparation of the maps and illustrations. To Miss Hedwig T. Kniker he is indebted for assistance in the paleontologic and stratigraphic determinations of the subsurface section. To Edgar W. Owen, he is indebted for helpful suggestions as to nomenclature usage.

[2] 354 Cavalier Avenue.

(Clemville) oil field, 15 miles northwest of the Gulf sulphur field, and 31 miles southwest of the West Columbia oil field.

HISTORY OF DEVELOPMENT

The Stoddard ranch, comprising about 10,000 acres, was submitted by its owners, early in 1931, for consideration as an oil and gas prospect, to the United North and South Development Company. During March of that year, the writer made a geological examination of this ranch, and selected the area surrounding the Buckeye townsite as showing stronger evidences of structure than any other part of this ranch.

The leasing of the area was started immediately after the writer's report was completed. Other companies, such as the Marland Oil Company, through Alexander Deussen, and the Humble Oil and Refining Company, were reported to have negotiated with the landowners for a lease contract in the past.

During September, 1931, F. E. Heatley was employed to make a magnetometer survey of this ranch.

On October 11, 1931, the first well on this prospect was spudded in. The intention originally was to drill it to the depth of 4,500 feet unless oil were discovered at lesser depth, to satisfy the lease contract on the Stoddard ranch. As shown in the type section (Fig. 2), several indications of uplift were revealed before this depth was reached. The Beaumont-Lissie of the Pleistocene was thinner by 90 feet than normally expected. The Lagarto member of the Pliocene was thinner by 300 feet than normal; and the Oakville, or Middle Fleming, of the Miocene showed a thinning of approximately 200 feet. These evidences of thinning are based on comparisons with another wildcat well in this region along the same strike.[3]

Since no oil or gas showing had been encountered, the drilling was continued. At the depth of 5,370 feet in an upper sand member of the Basal Fleming, a gas showing and an oil stain were encountered. But this showing was not of commercial value. Similarly, at the depth of 5,696 feet, a slight showing of oil and gas was found. The only showing of importance was found in the Lower Catahoula (Frio) formation at the depth of 7,765 feet, about 59 feet below the top of this formation. After repeated failures to bring in the well from a depth of 7,830 feet, the well was side-tracked and drilled to 7,951 feet. The sands between the depth of 7,765 and 7,926 feet showed oil and gas, but the section between 7,926 and 7,951 feet showed water. These water-bearing sands were plugged back. The sands of this pay sec-

[3] See footnote 5.

tion were thin lenses rarely exceeding 7 feet in thickness. About 27 feet of pure oil sand was recognized but, because of core loss, the pure sand thickness was estimated to be greater, though not more than 50 feet.

On August 31, 1932, after screen was set, and the washing of the screen was started, the well blew in unexpectedly and was out of control for 6 days, producing during this time, it was estimated, 2,000 barrels of oil per day. On September 11, 1932, the well was brought in under control and flowed 1,800 barrels of 39°A.P.I.-gravity oil through a ½-inch choke.

In the meantime, the prospective area was divided into 20-acre units. The discovery well was in Unit No. 1.

The second well, in Unit No. 5, located 996 feet N. 30°E. of the discovery well, was spudded in, December 6, 1932, and completed as a commercial producer at 7,858 feet on March 3, 1933. The initial daily production was 2,000 barrels of 37°A.P.I.-gravity oil on a ½-inch choke.

The top of the Lower Catahoula in this well was encountered 92 feet higher than in the discovery well (Fig. 3). The top of the Marine Miocene was only 56 feet higher than in the discovery well; the top of the Lagarto was only 10 feet higher. This indicates that the uplift increased gradually with depth, from near the top to the bottom of the vertical section (Fig. 3).

The top of the pay section occurred at 7,795 feet, about 181 feet below the top of the Lower Catahoula. This indicated that the upper part of the pay section in the discovery well did not contain oil sands in the second well. The strata producing oil in this well contained not more than 10 feet of pure sand, and were equivalent in part to those below the water level in the discovery well.

The third well, in Unit No. 6, located 1,040 feet N. 55°E. of Unit No. 5, was spudded in, February 19, 1933. This well showed greater uplift (Fig. 3) than any other well thus far drilled on this prospect, being 14 feet higher on the top of the Lower Catahoula than the second well. The stratigraphic section that produced oil in the discovery well did not show any sand bodies in this well. A sand streak between the depths of 7,851 and 7,866 feet showed good oil saturation, but, when screen was set, the test showed only salt water. This sand body is probably the same as the lower part of the producing formation in the Unit No. 5 well. This well was drilled deeper, attaining a depth of 9,450 feet on May 31, 1934, but no additional oil or gas showings were encountered. The formation at the bottom of the hole is Lower Catahoula in age.

The fourth well, Unit No. 14, located 1,210 feet S. 40°E. of the Unit No. 1 well, was begun on March 16, 1933. Structurally, this well is only 6 feet lower on the top of the Lower Catahoula than the Unit No. 5 well. Although some very thin oil-sand streaks were present between the depths of 7,700 and 7,860 feet, the well did not flow or indicate that it would make a commercial well on the pump. This well was drilled to a depth of 7,917 feet, but the occasional sand streaks below 7,860 feet, to the bottom of the hole, showed salt water.

The fifth well, in Unit No. 25, located ½ mile N. 80°E. of the discovery well and 1,650 feet S. 52°E. of the Unit No. 6 well, was begun on May 5, 1933. It encountered all the formations below the Marine Miocene definitely lower than any of the four preceding wells (Fig. 3). In fact, the top of the Lower Catahoula occurs 133 feet lower than in the Unit No. 6 well, the highest well thus far drilled.

The "pay" section occurring between 7,806 and 7,870 feet showed a few thin streaks of oil-saturated sand, but when tested did not flow, and the amount of oil shown was not enough to warrant a pumping installation because of the great depth. This well was drilled deeper, but all the sand streaks below the 7,870-foot level, to the bottom at 8,340 feet, showed salt water.

The sixth well was started, March 5, 1934, in Unit No. 4, and is located 950 feet northward from the discovery well and 950 feet west-northwest from the well in Unit No. 5, the second well. It encountered all the formations a few feet lower than in the discovery well, the top of the Lower Catahoula occurring at 7,713 feet. The bottom of the hole was at 7,852 feet when tested. The well produced 24 barrels on May 20, 1934, but the oil was accompanied by water. The closed-in pressure in this well did not exceed 125 pounds per square inch at the casing-head, whereas in the discovery well the original closed-in pressure exceeded 1,000 pounds per square inch. The failure of this well to make a commercial producer was probably due both to depletion of the sand and to poor sand conditions.

The seventh well, in Unit No. 58, was started July 19, 1934. It is located about 1,500 feet S. 75°W. of the discovery well. This well encountered the top of the Lower Catahoula (Frio) at 7,733 feet, and failed to show good sand bodies in the producing level of the Unit No. 1 well. The only promising sands occurred at, and below, 7,900 feet, but when tested showed salt water. The failure of this well to encounter oil sands between the depths of 7,800 and 7,870 feet further indicates that the Unit No. 1 producing sand is of small lateral extent.

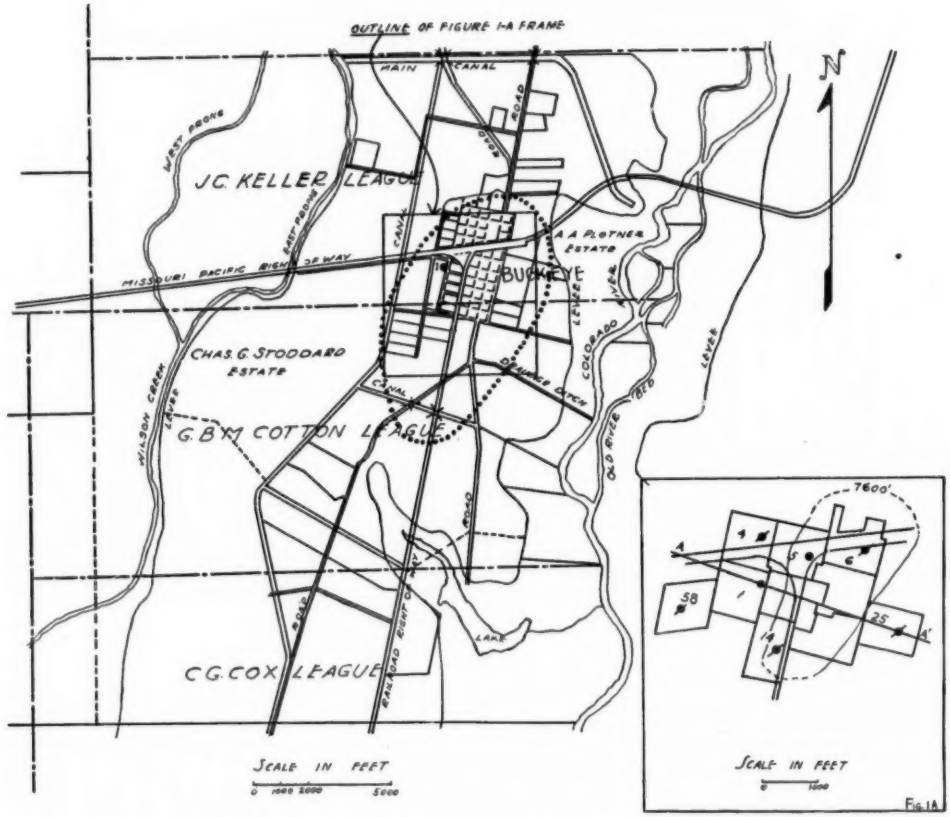

FIG. 1.—Buckeye area, showing outline of surface sand inlier (dots) and location of discovery well.
FIG. 1-A.—Subsurface contour map, showing 7,600-foot contour on top of Lower Catahoula (Frio), location of wells in their respective 20-acre units, and section *AA'* (Fig. 3).

SURFACE GEOLOGY

This area is on the Beaumont clay outcrop. The surface beds are of sands and clays abutting the Colorado River bottom alluvium about ½ mile east of Buckeye. What seems to be an abnormal condition in the surface beds is the occurrence of a sand inlier of an oval outline covering about 600 acres. This sand inlier is elongate north-northeast and south-southwest, and is bounded on the west and east by black clay land and on the north and south by sandy clays. The sandy clays in the northerly and southerly extensions, in general, have a lesser sand content than the soils of the inlier as outlined. This sand inlier suggests a domal uplift (Fig. 1), but the sand belongs to the Beaumont formation.

The topography of the area does not show any pronounced surface irregularities excepting at a point about 2,000 feet northwest of Buckeye Station, where a short northwest slope occurs in the sand inlier. This exception to the monotonous southeastward slope of the general terrane, when it is considered that it was probably not due to stream action, led the writer to regard it as a structural indication in connection with the sand inlier suggestion.

The drainage of the region is generally south-southeast. The Colorado River system drains the eastern part of this area and Wilson Creek the west side, thus forming a low interstream ridge upon which Buckeye is located.

GEOPHYSICS

A magnetometer survey of this area was made in September, 1931, by F. E. Heatley. This survey showed an uplift having an outline somewhat similar to the surface interpretation (Fig. 1), but the center of the magnetic uplift lies a short distance northeast of the center of the surface outline.

After the completion of the discovery well, both the torsion balance and the reflection seismograph were employed to make geophysical surveys, but the results of these surveys are at variance with those revealed by the drill.

SUBSURFACE GEOLOGY

The subsurface cross section (Fig. 3) shows that the west and east closure of the uplift fall within the boundaries of the surface outline (Fig. 1). This indicates that the true uplift, as revealed thus far, may be even smaller than suggested by the surface geology.

A contour map of the subsurface has been prepared, but the north and south closures have not yet been established by drilling. This contour map is shown in Figure 1-A.

FIG. 1-A.—Subsurface contour map, showing 7,600-foot contour on top of Lower Catahoula (Frio), location of wells n their respective 20-acre units, and section *AA'* (Fig. 3).

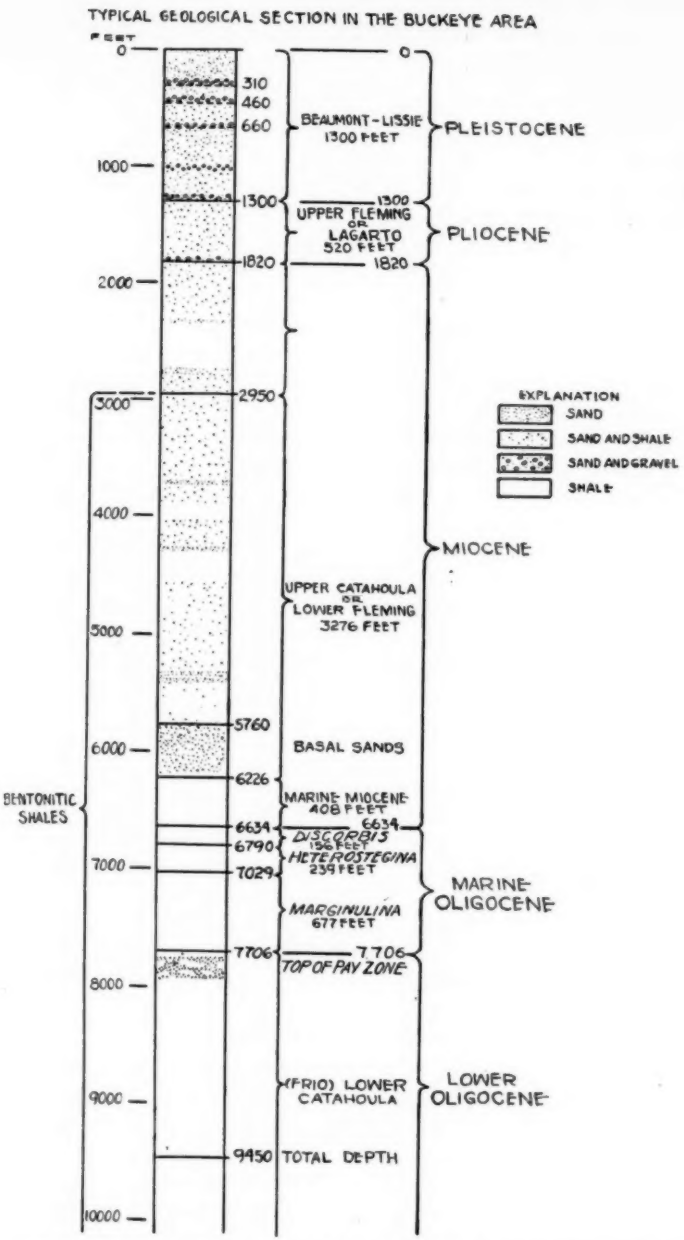

FIG. 2.—Buckeye geologic column taken from record of discovery well on Unit No. 1 to depth of 7,951 feet and extended to 9,450 feet from record of Unit No. 6 well.

Figure 2 gives Hedwig T. Kniker's determinations on the stratigraphic character of the drilled section in Stoddard No. 1, the discovery well of the Buckeye area, and of the Unit No. 6 well from 7,951 feet to 9,450 feet. The following topic on stratigraphy is a description of the lithologic and faunal characteristics based on Miss Kniker's work. A good set of drill-cutting samples was taken as drilling

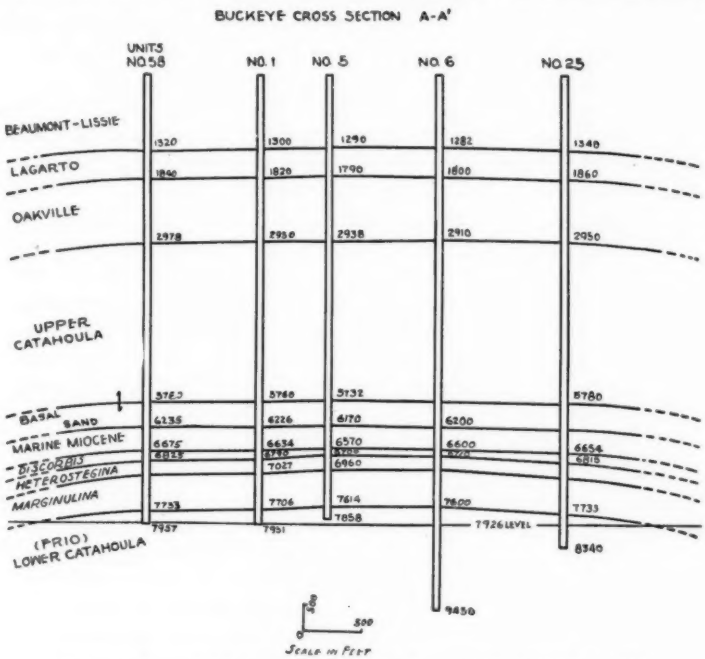

FIG. 3.—Approximately west-east profile along section *AA'* (Fig. 1-A).

progressed. No coring was done until a depth of 2,145 feet had been reached. Between this depth and 5,634 feet a few cores were cut, and from 5,634 feet to the total depth of 7,951 feet, the hole was cored almost continuously. In the section below 7,951 feet, the formation data from the Unit No. 6 well between 7,800 feet and 9,450 feet were taken for this report.

The nomenclature[4] of formations, as used in this report, is based on that used by authorities on Texas geology.

[4] E. H. Sellards, W. S. Adkins, and F. B. Plummer, "Cenozoic Systems," in "The Geology of Texas. I. Stratigraphy," *Univ. Texas Bull. 3232*, Vol. 1 (1932).

STRATIGRAPHY

PLEISTOCENE

Beaumont-Lissie.—The formations from the surface to the 1,300-foot depth are tentatively assigned to the undifferentiated Beaumont-Lissie, and are divided into four distinct zones, each with definite characteristics, that have been traced into the adjoining county on the northeast[5]. These 1,300 feet of clay and sand of Beaumont-Lissie aspect probably represent the greater part of the total normal thickness of Pleistocene in this area.

The upper 310 feet consist chiefly of orange-colored, medium-coarse, loose sand, similar to the sand on the surface, but the lower part of the 310 feet shows an increase in reddish clay. A few shell fragments and smooth ostracods are present in this zone. A basal unconformity is indicated by the presence of gravel at 310 and 320 feet.

The next 150 feet consists of red calcareous clay containing fine and coarse, pinkish gray sand and light-colored limestone nodules. The fossils are *Rotalia beccarii* (Linné), *Elphidium* sp., smooth ostracods, shell fragments, and reworked Cretaceous *Foraminifera* and aragonite prisms. Between the depths of 440 and 460 feet are found some chert and quartz gravels, which indicate a basal unconformity for this zone.

The next 200 feet consists chiefly of red and green calcareous clay, containing white and bluish limestone nodules. The sand is gray-to-pinkish gray in color, fairly coarse in texture, and occurs in varying amounts. The fossils are *Rotalia beccarii* (Linné), and blue oyster and other shell fragments. At 620–660 feet, large amounts of gravel indicate an unconformity, and mark the base of the third zone.

The top of the fourth zone, at 660 feet, shows an increase in the limestone nodules and a decrease in sand. This zone, which extends down to the 1,300-foot depth, consists of red and green calcareous clay, containing small white and blue limestone nodules with small amounts of pinkish gray and gray sand to the depth of 1,020 feet, with larger amounts of fairly coarse sand below this depth. Among the fossil *Foraminifera* is *Rotalia beccarii* (Linné). Among the larger forms are *Rangia cuneata* (Gray), *Pecten*, *Mulinia*, blue oysters, *Balanus*, *Dentalium*, gastropods, and miscellaneous shell fragments.

Coarse sand and a little gravel at 1,280 feet may indicate an un-

[5] Thirty-five miles northeast of Buckeye, the United North and South Development Company's Lewis No. 1, Brazoria County, Texas, encountered a similar zoning in the Beaumont-Lissie section, and in addition, a 300-foot sandy zone not recognized at Buckeye, having a total thickness of 1,390 feet, 830 feet of Lagarto, and 1,300 feet of Middle Fleming or Oakville. The paleontologic determinations were made by Hedwig T. Kniker.

conformity at the base of the Beaumont-Lissie section in this well. The total thickness of this Pleistocene section is 1,300 feet, which may be thinner by 90 or more feet than is normal for this region.[6]

PLIOCENE

The Upper Fleming, or Lagarto, directly underlies the Beaumont-Lissie in this well. No doubt an unconformity marks this contact, because of the presence of a coarse sand and gravel bed at the contact between the Beaumont-Lissie and the Lagarto formations.

The term Fleming is here used as a group name, embracing all the closely related sediments from the top of the Lagarto to the top of the Marine Miocene green shales.[6]

These Lagarto beds are chiefly red and light green calcareous clays bearing many limestone nodules, some pyrite, and also unevenly sorted, generally fine, clear-to-pinkish sands. The fossils consist of sparse, reworked Cretaceous *Foraminifera* and aragonite prisms. The total thickness of this formation in this well is 520 feet, which indicates a thinning of 300 feet or more. The base is at 1,820 feet. No evidence of a pronounced unconformity was found at the base of this formation.

This formation is tentatively regarded as of Pliocene age, but is not markedly dissimilar to the underlying Miocene beds.

MIOCENE

Oakville.—The next formation encountered is the more sandy middle Fleming, or Oakville, equivalent. The clays and sandy clays are calcareous, mottled red, yellow, and green, and contain white, red, yellow, and blue limestone nodules, and a little pyrite. The sand is medium coarse-grained and pinkish gray, the grains being unevenly worn and slightly polished. Reworked Cretaceous *Foraminifera* and aragonite prisms are common, and here and there a *Chara* fruit-case is present.

The main differences between the Lagarto and the Oakville members are that in the clays of the latter the yellow color is very marked, the sand grains are generally coarser, less angular, and of darker colors. The limestone nodules show a greater variety of colors, and reworked *Foraminifera* and aragonite prisms are more abundant. The thickness of this member is 1,130 feet, and the base occurs at 2,950 feet. This thickness of the Oakville member represents a slight thinning, probably 200 feet less than its normal thickness for this area. No evidence of unconformity was found at the base of the Oakville.

[6] E. H. Sellards, W. S. Adkins, and F. B. Plummer, *op. cit.*, pp. 728–29.

Upper Catahoula.—The formation underlying the Oakville is for convenience called the Lower Fleming, and the greater part of it is very probably the equivalent of the Upper Catahoula. This group of beds of shallow-water marine origin extends from 2,950 feet to 6,226 feet, and consists of thick deposits of vari-colored shales and clays with some sands down to 5,760 feet. This part is the Lower Fleming proper and is underlain by 466 feet of sandy strata with some shales, referred to as the Basal Fleming sands of this Upper Catahoula (Lower Fleming) formation.

The upper, greater part overlying these Basal Fleming sands consists of mottled maroon, yellow, green, and gray, unctuous or bentonitic shales and some clays which contain varying amounts of sand in places. Several zones of sand are present as shown in the geologic section of this well (Fig. 2). Between 5,373 and 5,411 feet, there is a sand and sandrock bed with an oil and gas showing. The shales are calcareous throughout and bentonitic in character. Small quantities of pyrite are of common occurrence, but limestone nodules are not so numerous as above. The sediments become more bentonitic toward the lower part of the group. Volcanic ash occurs sparingly. Gypsum is present in the shales between 3,160 and 3,320 feet; anhydrite in small amounts is found between 4,150 and 4,650 feet; and both gypsum and anhydrite are found between 4,950 and 5,210 feet. The gypsum and anhydrite are apparently disseminated throughout the clays in these zones and do not form distinct beds. A little lignite is present in the shales in a few places.

This extremely thick section of bentonitic or pyroclastic related deposits is regarded as being in general the down-dip equivalent of the tuffaceous sediments on the Upper Catahoula outcrop.

The washed residue of samples differs considerably from that of samples from overlying deposits. Most of the sands are fine, gray, and grayish in color, although some pinkish sand and streaks of coarser sand are present. This unit being a deeper-water deposit, the shales, generally, contain less sand than the overlying Oakville clays. Reworked Cretaceous *Foraminifera* and aragonite prisms are plentiful in the upper fourth of the unit, but deeper become less numerous, although they are present to the base. Oysters and *Rotalia beccarii* (Linné) are fairly abundant throughout. A few *Chara* fruit-cases, gastropods, and pelecypods are present. Ostracods occur from 4,683 feet down to the base, and, in the lowermost few hundred feet, *Elphidium*, *Haplophragmoides*, and *Discorbis* also are present.

Basal Fleming sands.—This unit extends from 5,760 to 6,226 feet, and composes the basal sands of the Upper Catahoula. It consists

of three members of shallow-water marine origin and is for convenience referred to as the Basal Fleming sands. The topmost 81 feet are friable, pure, grayish, medium-grained sandstones which showed gas when drilled through. The next 176 feet are green, bentonitic, sandy shales with sand streaks, the sand being like that in the overlying member, medium-grained and slightly polished. Lignite is present in the lower 100 feet. At the base a lignite bed more than a foot thick was penetrated. Small quantities of volcanic ash are present, and a bed of bentonite was noted in the basal part. Some oysters and ostracods are present in the shale. The lowest member, from 6,017 to 6,226 feet, consists of gray, soft sandstones with streaks of hard sandstone. The sand in this member is darker than that in the overlying beds, and the grains are more angular. The fossils in this lower member consist of fragile pelecypod shells and a few reworked aragonite prisms. This thick sand body showed neither oil nor gas. This member marks the transition from shallow-water to deeper-water marine deposition and probably represents a major unconformity.

Marine Miocene.—This formation, between 6,226 and 6,634 feet, consists principally of marine, green shales, in sharp contrast to the vari-colored shales in the overlying formation. In general, these beds consist of greenish gray, bentonitic, slightly calcareous-to-non-calcareous shales which are very sandy between 6,226 and 6,450 feet, but contain only small quantities of sand in the basal part.

Rotalia beccarii (Linné) and reworked Cretaceous *Foraminifera* and aragonite prisms are present only in the upper sandy beds of the Marine Miocene, and marine *Foraminifera* become more abundant below the 6,450-foot depth. *Lenticulina*, represented by several species, is the predominating genus in the fauna. The more important fossils present are the following.

Lenticulina cf. *L. rotulata* (Lamarck)*
Lenticulina vicksburgensis (Cushman)
Lenticulina vaughani (Cushman)
Eponides cf. *E. antillarum* (d'Orbigny)
Nonion grateloupi (d'Orbigny)
Siphonina sp.
Cibicides floridanus (Cushman)
Elphidium sp.
Globigerina spp.
Uvigerina spp.
Discorbis cf. *D. bertheloti* d'Orbigny
Textularia foliacea Heron-Allen and Earland var. *reedi* Applin

* In the foregoing list and in succeeding fossil lists, the genera are arranged according to abundance of specimens present. This also holds for different species listed under the same genus.

OLIGOCENE

Discorbis zone.—The *Discorbis* zone consists of marine, grayish green and greenish gray, slightly calcareous, unctuous or bentonitic

shales containing negligible amounts of fine gray sand and varying amounts of pyrite. At the contact between this zone and the Marine Miocene above, there was only a very slight change in the color of the shale. However, there was a distinct faunal break. Even the manner of preservation of the fossils was different. The color of the Miocene *Foraminifera* is yellow, but that of the *Discorbis* zone forms is generally gray.

This zone extends from 6,634 to 6,790 feet, a total of 156 feet. Normally, this unit should have greater thickness.

The predominating foraminifer of this zone is a species of *Cibicides* similar to, but much larger than, *C. mississippiensis* (Cushman). The more common forms comprising this fauna are the following.

Cibicides sp.
Gyroidina cf. *G. soldanii* d'Orbigny
Globigerina spp.
Eponides sp. (similar to the one in the Marine Miocene)
Lenticulina cf. *L. rotulata* (Lamarck)
Lenticulina vicksburgensis (Cushman)
Lenticulina vaughani (Cushman)
Uvigerina spp.
Nonion grateloupi (d'Orbigny)
Elphidium sagrum (d'Orbigny)
Cibicides floridanus (Cushman)
Discorbis cf. *D. vilardeboana* d'Orbigny

Heterostegina zone.—The *Heterostegina* zone extends from 6,790 to 7,029 feet and consists almost entirely of marine, greenish gray, slightly calcareous, unctuous or bentonitic pure shales. A thin streak of dense, grayish limestone, not more than a few feet thick, is present at the very top of the zone, and some limestone streaks were noted in the shale 100 feet below the top. This is apparently all the limestone that is present, in contrast to thick limestone deposits that are found in many wells drilled on shallow salt domes.[7] This unit differs from the overlying and underlying depositional units in being practically sandless. Heavy pyrite is present at different levels, suggesting thinning of the section. In hand specimens, the *Heterostegina* shales can not be distinguished from the *Discorbis* shales.

There is a pronounced faunal change at the contact of the *Heterostegina* and *Discorbis* zones. As is characteristic, the *Discorbis* zone fauna consists of an aggregation of rather small, more or less fragile species. The *Heterostegina* zone assemblage, however, is composed of larger and, generally, more robust species. The two zones show many differences in species. *Heterostegina* cf. *H. antillea* Cushman occurs sparingly in the limestone section in the upper part of this zone. The more common forms are the following.

[7] E. H. Sellards, W. S. Adkins, and F. B. Plummer, *op. cit.*, p. 709.

Eponides sp. (different from *E.* sp. noted in *Discorbis* zone)
Lenticulina spp.
Lenticulina vicksburgensis (Cushman)
Lenticulina cultrata (Montfort)
Lenticulina vaughani (Cushman)
Cibicides sp.
Ostracods (three species)
Gyroidina cf. *G. soldanii* d'Orbigny
Globigerina spp.
Textularia spp.
Siphonina sp.
Bolivina sp.
Uvigerina sp.
Dentalina cf. *D. jacksonensis* (Cushman and Applin)
Heterostegina cf. *H. antillea* Cushman

Marginulina zone.—The sediments from 7,029 to 7,706 feet belong to the *Marginulina* zone and consist of marine, gray, and greenish gray, unctuous or bentonitic shales which are variably calcareous to non-calcareous in general. In contrast to the overlying non-sandy *Heterostegina* zone, this zone has a small quantity of silty sand present in the shale throughout, with sandier areas occurring here and there below 7,503 feet, and the first true sandstone being present in the basal part of the unit at 7,685 feet. Pyrite occurs irregularly throughout this formation, but not so plentifully as in the beds of the overlying zone. Glauconite is present in the basal part, from 7,584 to 7,706 feet.

The faunas of the *Marginulina* and *Heterostegina* zones have many common forms. However, in faunal association the two also show the following distinct differences. *Marginulina* cf. *M. philippinensis* Cushman is common from top to base in the former zone. This zone also is characterized by an abundance of *Uvigerinas*, a small species of *Cibicides*, and different species of *Textularia* from those present above. *Gyroidina* cf. *G. soldanii* d'Orbigny, which is a common form in the two overlying zones, is absent, with the exception of a few specimens which are present at the top of the zone. The large species of *Cibicides* which is abundant in both the *Discorbis* and *Heterostegina* zones is absent in the *Marginulina* zone, and beaded *Lenticulinas*, which are common forms in the three marine units above, are very sparse in the latter zone.

Lower Catahoula (Frio).—The top of this formation is marked by a change from generally medium-greenish gray, slightly calcareous, unctuous shales in the overlying beds to lighter greenish gray and gray, slightly calcareous to non-calcareous, very bentonitic shales containing a shallower marine foraminiferal fauna. Since the overlying beds are of deeper-water marine origin, this contact is considered unconformable.

These shales are marked by a larger sand content than in the overlying *Marginulina* zone beds, with the added presence of thin lenticular sand members. The sand is generally light gray in color and very fine to fine-grained in general, although coarser-grained streaks are present. Glauconite is present in the upper 125 feet of the unit. Volcanic ash and lignite are first present at approximately the base of the glauconite-bearing beds and persist to the bottom of the hole. The sandstones are very ashy in places. This formation was penetrated to a depth of 7,951 feet, a total of 245 feet in the discovery well.

The sand bodies between 7,756 and 7,926 feet contained oil. The sand below 7,926 feet contained salt water and a very slight oil odor.

These beds contain a well developed shallow-water microfauna, which is persistent and fairly abundant in some strata. It is very different from the overlying *Marginulina* zone fauna. Most of the species are small, and several genera are represented. A small, distinctive species of *Cibicides* which is nearest to *C. antiqua* (Cushman and Applin) is by far the most abundant form. The important fossils present are the following.

Cibicides sp.
Nonion spp.
Siphonina spp.
Textularia spp.
Haplophragmoides spp.
Lenticulina sp.
Eponides sp.
Rotalia beccarii (Linné)
Discorbis sp.
Globigerina sp.
Amphistegina lessonii d'Orbigny
Marginulina cf. *M. philippinensis* Cushman
Ostracod spp.

In subsurface sections, the term Frio is generally used as a group name to include the deposits lying between the base of the marine Oligocene beds and the top of the Vicksburg, but the term Lower Catahoula seems to be a better designation now. In the Refugio field, Refugio County, Texas, the Lower Catahoula (Frio) is composed of several lithologic units.[8]

In the Buckeye area, two other wells have penetrated the section deeper than the discovery well on which the foregoing section is based. These two wells, after drilling through approximately 700 feet of the Lower Catahoula unit previously described, encountered a change in the lithologic character of the beds. Below this point occur darker shales with streaks of very ashy sandstones and of bentonite. These

[8] Hedwig T. Kniker, personal communication.

shales are highly bentonitic, slightly calcareous-to-non-calcareous, and contain some glauconite and lignite. It seems that these darker shales represent a second member of the Lower Catahoula section. The *Foraminifera* are of the same type as those mentioned previously. Not enough specimens have been seen to determine whether this fauna as a whole differs from the fauna found in the overlying beds.

CORRELATION PROBLEMS

As far as the writer is aware, the true age of the *Discorbis*, *Heterostegina*, and *Marginulina* zones is not positively known. Originally all three were referred to the Middle Oligocene on the basis of the *Heterostegina* form present in the middle zone. This foraminifer was identified as a species occurring in the Middle Oligocene of the West Indies.[9] However, there is no proof that the range of this form, *Heterostegina antillea* Cushman, is confined to the Middle Oligocene everywhere in the general region. Also, certain differences between the faunal associations of the three zones make it questionable whether all three should be considered as being closely related in age.

In the Buckeye area, fortunately, the three Marine Oligocene zones are represented by well developed deep-water faunas which differ considerably from the shallower-water aggregations of fossils found farther inland. *Discorbis* and *Heterostegina*, which are generally the key *Foraminifera* of the upper two zones, respectively, are very rare forms in the faunas.

The age of these five distinct units, namely, Marine Miocene, *Discorbis*, *Heterostegina*, and *Marginulina* zones, and the Lower Catahoula, is determined solely by paleontology. The age of the Marine Miocene fauna can hardly be questioned. An examination of the list of *Foraminifera* shows that it is a typical Miocene group. This means that the overlying Lower Fleming or Upper Catahoula beds must be referred to the Miocene. And, farther inland, all deposits at least down to the *Discorbis* zone must be considered as being of Miocene age.

The faunas of the *Heterostegina* and *Marginulina* zones have much in common and may be closely related in age. According to published classifications, these two units are generally referred to as belonging to the Middle Oligocene. *Lenticulina cultrata* (Montfort), known from the Vicksburg of the southeastern United States and the Oligocene of Mexico, is well represented in both zones.[10] Other species of smooth

[9] Alva Christine Ellisor, "Jackson Group of Formations in Texas with Notes on Frio and Vicksburg," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 11 (November, 1933), p. 1326, footnote 30.

[10] Hedwig T. Kniker, personal communication.

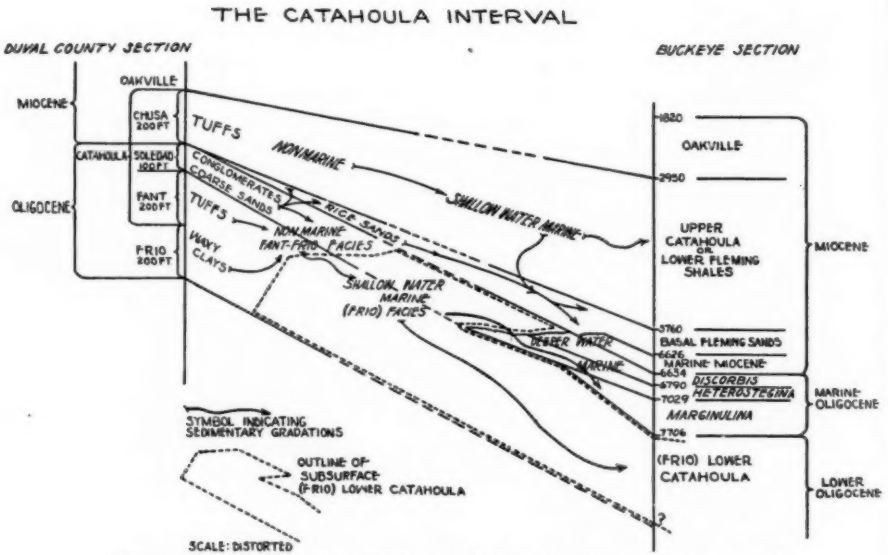

FIG. 4.—Diagram illustrating tentative correlation of Catahoula outcrop in Duval County with Catahoula sediments at Buckeye.

Lenticulinas, the several species of *Textularia* present, and other distinctive species resemble forms known to occur in the Oligocene. The aspect of the two faunas is entirely different from any described Miocene faunas.[10]

Lithologically, there is no unconformity between the Miocene and Oligocene in the green shale section underlying the Basal Fleming sands of the Upper Catahoula. The major faunal change occurs at the contact between the *Discorbis* and *Heterostegina* zones. As can be seen in the foregoing fossil lists, the faunas of the Marine Miocene and the *Discorbis* zone have much in common. *Cibicides* sp. and *Gyroidina* are present in the latter and range down into the *Heterostegina* zone, but neither of these two is a typical Oligocene form. The *Discorbis* zone fauna differs greatly from the two underlying Oligocene faunas, and suggests a possible Miocene age.

In south Texas, where shallower-water phases of these zones are present, the faunas of the Marine Miocene and the *Discorbis* zone are very similar and are difficult to differentiate. For this reason, the top of the *Heterostegina* zone is selected as the more satisfactory point for correlation purposes in that area.

At Buckeye, the Lower Catahoula contains a shallow-water fauna which has no diagnostic fossils that would establish its true age.

Catahoula interval.—The outstanding common characteristic of the formations of this interval is the generally uniform bentonitic character of the shales. From the top of the Upper Catahoula at 2,950 feet down through the Marine Miocene, the Middle or Marine Oligocene, and into the Lower Catahoula to a depth of 9,450 feet, the bentonitic shales occur uniformly. The upper 3,276 feet of this section obviously is of Upper Catahoula age, and is marked by a basal sands section 466 feet thick, which indicates a sedimentary unconformity. These beds are of shallow-water marine origin, and two zones of volcanic ash were noted.

The formations between 6,226 and 7,706 feet comprising the Marine Miocene and the *Discorbis*, *Heterostegina*, and *Marginulina* zones of the Marine Oligocene, although composed chiefly of bentonitic shales, are definitely of deeper-water marine origin and contain a marine fauna.

The Lower Catahoula formation is of shallow-water marine origin, is even more bentonitic than the overlying beds, and contains considerable amounts of volcanic ash. The Vicksburg formation has not been reached.

This bentonitic character of all the shales and the occurrence of volcanic ash suggest that these beds, which are more than 6,250 feet

thick, belong to a period of apparently uninterrupted volcanic activity. The upper 3,684 feet down to the top of the *Discorbis* zone are unquestionably of Miocene age. The beds below the Marine Miocene are assigned to the Oligocene on the basis of present correlations,[11] but the age of these beds may be Miocene down to the top of the Vicksburg. If Oligocene time was not marked by volcanic activity, then the entire Catahoula interval above the Fayette on the outcrop and above the Oligocene Vicksburg in the subsurface may be of Miocene age.

In order to correlate this great thickness of pyroclastic related sediments with Catahoula strata on the outcrop, it becomes necessary to employ theory because but few pertinent diagnostic facts are available. Fossil evidence is too meager to correlate the surface Catahoula beds with their probable equivalents as far down dip as Buckeye. But, on the bases of lithologic and general stratigraphic character, the writer believes that a satisfactory correlation can be suggested. A diagrammatic presentation[12] of this suggested correlation is shown in Figure 4.

An explanation of the theories expressed by this diagram is that the Chusa tuffs become progressively more argillaceous down dip with concomitant thickening of the beds to account for an increase from approximately 200 feet at the outcrop to the 2,810 feet of its probable equivalent, the Lower Fleming or Upper Catahoula clays in the Buckeye subsurface. The Basal Fleming sands, or rather, the basal sands of the Upper Catahoula, are correlated tentatively with the Catahoula "rice sands" of East Texas.

Furthermore, the Soledad conglomerates and coarse sandstones, although perhaps 100 feet thick at the outcrop, are marked by upper, interformational, and basal unconformities and disconformities.[13] The very fact that this formation contains conglomerates and coarse sandstones suggests the probable presence of other unconformities not readily recognized. This zone of unconformities suggests that during the Soledad epoch several hiatuses are represented. During these hiatuses the conditions of deep-water marine sedimentation prevailed undoubtedly far down dip from the outcrop. The sediments of both the Chusa and the Fant suggest the prevalence of uninter-

[11] Alva Christine Ellisor, *op. cit.*, p. 1,326.

[12] Thomas L. Bailey, "The Gueydan, A New Middle Tertiary Formation from the Southwestern Coastal Plain of Texas," *Univ. Texas Bull. 2645* (December 1, 1926), pp. 80–88. For ease of comparison, the writer chose the Duval County section of the Catahoula outcrop for the landward Catahoula interval.

[13] Thomas L. Bailey, *op. cit.*, pp. 80–86.

rupted depositional conditions, but those of the Soledad suggest several interruptions because of its conglomeratic character.

This Soledad interval, with its hiatuses, could easily be the time equivalent of the Catahoula "rice sands" epoch in East Texas and the Basal Fleming sands, the Marine Miocene, and the Middle or Marine Oligocene epochs at Buckeye. The writer's belief, based on the principle of basinward gradational changes in lithologic character, is that the Soledad surface sediments grade rapidly down dip into a nonmarine to shallow-water Frio-Fant facies that can not be differentiated readily from the underlying Frio.[14] Farther down dip the shallow-water marine conditions graded into deeper-water marine conditions. This accounts for the subsurface Frio facies of the down dip interval apparently merging with the marine deposits between the Upper and the Lower Catahoula sediments at Buckeye.

The Soledad is regarded as of upper Frio Oligocene age and as the equivalent of the basal Catahoula "rice sands" or Chita sands[15] in East Texas. In the light of this attempted correlation, however, it seems quite probable to the writer that the Chita sands on the outcrop may be the equivalent of the Basal Fleming sands at Buckeye. During the time of Basal Fleming deposition, the Buckeye area was in the transitional stage from deep-water marine to shallow-water marine shale sedimentation. It is probable that this transition occurred at the close of Soledad time, and that the Catahoula "rice sands" or Chita sands were deposited contemporaneously. At Buckeye the Basal Fleming sands are generally of medium-angular grain and of massive bedding, thus showing a close relation to a coarse sand deposition, but the sands of the Lower Catahoula are generally fine-grained and thinly bedded and suggest no such relation.

It is not the writer's intention to offer the foregoing suggested correlations as proved facts. It is hoped that these suggestions may encourage investigations that yield correct and authenticated proof of a true correlation.

RESERVOIR CONDITIONS

The best reservoir conditions encountered in the Buckeye section exist in the Basal Fleming or Upper Catahoula basal sands (Figs. 2 and 3), but these blanket sands, probably because of insufficient uplift, did not produce oil or gas. The sands in the producing zone of the Lower Catahoula were not in large extensive bodies, although these were capable of commercial oil production in the first two wells.

[14] Alva Christine Ellisor, *op. cit.*, p. 1,326.

[15] E. H. Sellards, W. S. Adkins, and F. B. Plummer, *op. cit.*, p. 717.

The extreme thinness of these sand lenses and the fact that these were not blanket sands render this pay section in this field a reservoir that is subject to rapid depletion under conventional producing methods. The oil closure of the upper part of the pay section is about 250 feet at the crest of the uplift as determined by the Unit No. 1 water table, but this was probably not sufficient to trap a large accumulation.

If the 7,926-foot depth in Unit No. 1 is at the true water level, then the sands below 7,870 feet in the other wells should have contained oil to the depth of 7,926 feet. The fact that these contained only water below the 7,870-foot depth suggests strongly that the uplift was never completely filled with oil. The Unit No. 6 well cored an oil sand between 7,851 and 7,866 feet, which when tested, showed only water, but this sand may have been drained by the well in Unit No. 5, which had produced 116,810 barrels of oil and gone to water before the Unit No. 6 well was tested. The next two wells had a very poor oil-sand section in the upper part of the pay zone, but the better sand bodies below 7,870 feet contained only water.

The sixth well in Unit No. 4 did not indicate as favorable reservoir conditions in the pay section as the first and second wells, and none of the sands cored in the seventh well showed oil.

These seven wells, widely located on a small structure, conservatively estimated by the writer to cover 600–800 acres, can not be regarded as proving the entire uplift. The fact that only two of these seven wells were commercial producers does not indicate the presence of a very valuable reservoir of oil in this horizon.

The flowing pressures in the discovery well ranged from a maximum of 1,200 pounds per square inch during the early flowing stages to 300 pounds when it ceased flowing. In the Unit No. 5 well, the maximum flowing pressure was 740 pounds per square inch during the early flowing stage, but dropped to 75 pounds the day before it eventually ceased flowing production. In both wells, the flowing pressure decreased as the water percentage increased. The water percentage during the flowing stages ranged from less than 2 to 50 per cent in both wells, the wells ceasing to flow as soon as the water percentage exceeded 50 per cent. The temperature of the oil ranged from 76°F. to 85°F. in both wells as long as the water percentage remained less than 10 per cent, but increased to 100°–124°F. as the water percentage rose above 10 per cent.

DRILLING METHODS

Rotary equipment was used to drill all the wells. The first well was drilled with 4-inch drill pipe to the casing seat above the pay zone.

The other wells used 5-inch drill pipe to the top of the pay section; and 3-inch drill pipe was used to complete the wells. In the discovery well about 1,000 feet of 10-inch surface casing was set, followed by 6-inch casing to the top of the productive zone. The next four wells had about 40 feet of 20-inch casing, about 1,400 feet of $13\frac{3}{8}$-inch casing, about 5,700 feet of $9\frac{5}{8}$-inch casing, and about 7,700 feet of 7-inch casing, respectively, thus increasing the casing costs in each of these four wells to almost twice that of the discovery well. The seventh well has 40 feet of 20-inch casing and 2,400 feet of $13\frac{3}{8}$-inch casing. No other casing was set in this well.

PRODUCTION

Table I gives the oil production, by months, of the two producing wells.

TABLE I

Unit No. 1, Discovery Well		*Unit No. 5, Second Well*	
Month	*Barrels*	*Month*	*Barrels*
1932		*1933*	
September	15,979	March	39,812
October	39,375	April	15,794
November	27,310	May	8,280
December	21,965	June	26,204
		July	26,720
1933			
January	3,212	Total	116,810
June	50,256		
July	37,299		
August	27,316		
September	14,941		
October	7,934		
Total	245,587		

The total production for both wells, as shown by Table I, is 362,397 barrels.

The total oil production to date slightly exceeds these totals, because both the Unit No. 1 and Unit No. 5 wells have since produced small amounts of oil through swabbing and pumping methods.

The gas and oil ratio of both wells averaged about 1,800 cubic feet of gas to one barrel of oil during the best producing periods.

The wells were producing on variable-sized chokes ranging from $\frac{1}{4}$-inch to $\frac{9}{16}$-inch in general. Because of the operator's desire to produce the maximum amount of oil daily consistent with freedom from sand cutting out the screen, the principles of conserving the reservoir energy, by curtailing the daily production properly, were not observed.

Table II gives, in part, an analysis of the Buckeye crude petroleum as determined by the Fort Worth Laboratories, of Fort Worth, Texas.

TABLE II

ANALYSIS OF BUCKEYE CRUDE PETROLEUM

Gravity at 60° F., 38.5°A.P.I. Sulphur, 0.10 per cent
Initial boiling point, 140°F. Color, brown

Summary of Yield in Distillation Test

Product	*Per Cent*	*Gravity at 60°F.*
Gasoline	25	55.0° A.P.I.
Kerosene	20	43.6
Distillate	15	38.8
Gas-oil	20	34.2
Wax distillate	15	27.8
Residue	5	
	100	

Summary of Yield in Cracking Test

(Basis 29.8° A.P.I. gravity topped crude representing 61.7 per cent of crude oil received)

Product	*Ultimate with Recycling Per Cent*
Gasoline	58.0
Fuel oil	32.0
Loss (gas and coke)	10.0
	100.0

Properties of Resulting Gasoline
Gravity, 55.0° A.P.I.
Initial boiling point, 95°F.
End point, 437°F.

The salt water produced with the oil from the (Frio) pay section during the declining stage of the flowing periods of both wells was of the same general character. Even the brine in the wells that did not produce oil from this pay section shows the same general mineral content as that of the producers. No hydrogen sulphide has been noted in these waters.

Table III shows, in part, an analysis of water taken from the discovery well, as determined by the Fort Worth Laboratories, Fort Worth, Texas.

TABLE III

Unit No. 1 Well, Buckeye, Texas (October 24, 1933)

Hypothetical Combination	*Parts Per Million*	*Grains Per U.S. Gallon*
Calcium carbonate	1,350.0	78.20
Calcium sulphate	71.0	4.12
Calcium chloride	939.0	54.45
Magnesium chloride	683.2	39.60
Sodium chloride	50,311.3	2,918.50

CONCLUSION

This field does not give promise of being a major oil reserve. It is possible that with continued drilling a few wells may produce oil on this uplift, in addition to the first two producers. Of the seven wells completed (December 27, 1934), only two were commercial producers. and these are now producing oil by pumping. This indicates that the oil accumulation on this uplift occurs in exceedingly irregular sand lenses of small areal extent. The trap formed by this uplift may be too young to have been completely filled with oil.

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TATUMS POOL, CARTER COUNTY, OKLAHOMA[1]

GLENN GRIMES[2]
Oklahoma City, Oklahoma

ABSTRACT

This pool is to be regarded as flank production of the great Arbuckle anticlinorium. Information and evidence are introduced to show that the production is from beds which have overlapped an old eroded surface, and also that the upper part of the producing sand is locally an erosional surface. The pool has a producing area of about 1,800 acres, although an approximate maximum of only 150 acres would be productive if it were not for the fact that the pay sand is sealed up the dip.

INTRODUCTION

The development of the Tatums pool has aroused a great deal of interest because it has been recognized as a distinct type of accumulation, namely, shore-line accumulation. This pool affords an important stratigraphic link between the Carter County pools and the Arbuckle Mountains.

Location.—The Tatums pool is located in T. 1 S., 2 and 3 W., Carter County, Oklahoma, about 35 miles east of Duncan, the better part of the production being in and near Sec. 24, T. 1 S., R. 3 W.

HISTORY

The pool is named from a negro town in Sec. 12, T. 1 S., R. 3 W.

The discovery well, Pollock No. 1, located in the SW. ¼, SW. ¼, SE. ¼ of Sec. 14, T. 1 S., R. 3 W., was completed by the Magnolia Petroleum Company on January 14, 1927, with an initial production of 25 barrels. Prior to the drilling of Pollock No. 1, at least three tests had been completed as dry and all at present have been proved to be within ¼ mile or less of the producing area.

The present producing area of the Tatums pool is about 1,800 acres with approximately 183 wells. The customary location is one well in the center of each 10 acres. The Oklahoma Corporation Commission potential of May 1, 1934, was 32,001 barrels from 183 wells.

[1] Presented before the Association at the Dallas meeting, March 24, 1934. Manuscript received, January 2, 1935.

[2] Geologist, Wirt Franklin Petroleum Corporation and Cromwell-Franklin Oil Company.

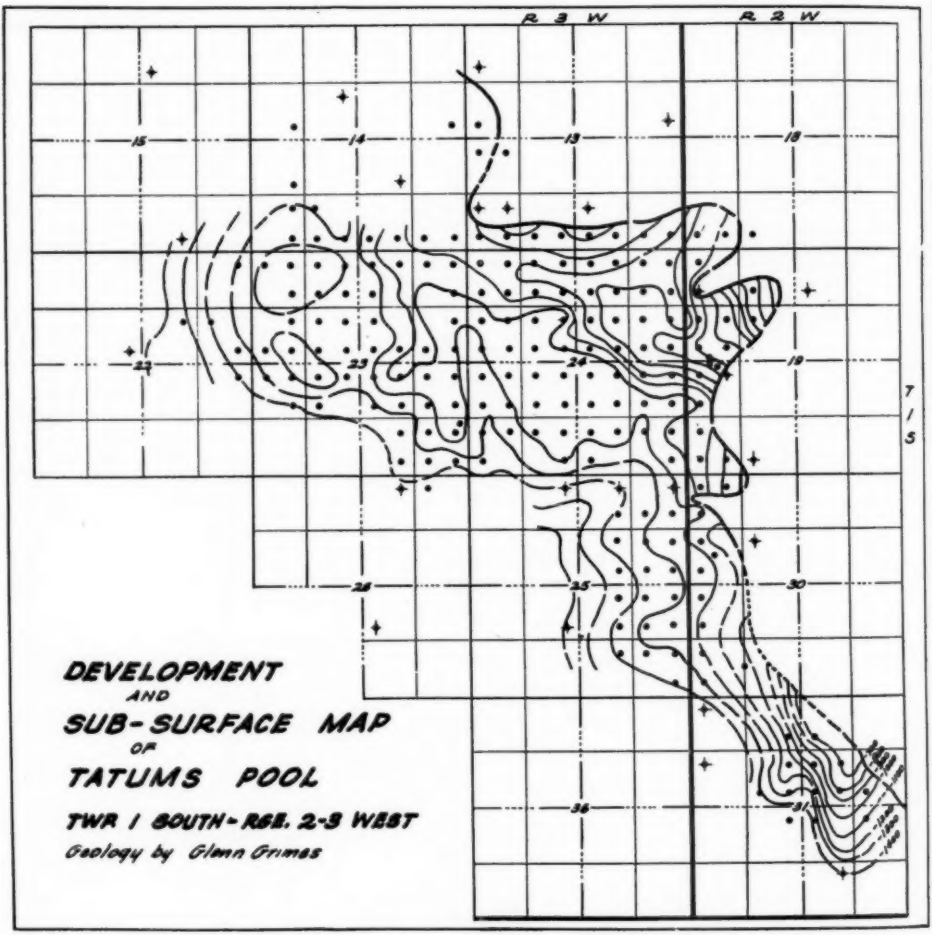

FIG. 1.—Development and subsurface map of Tatums pool.

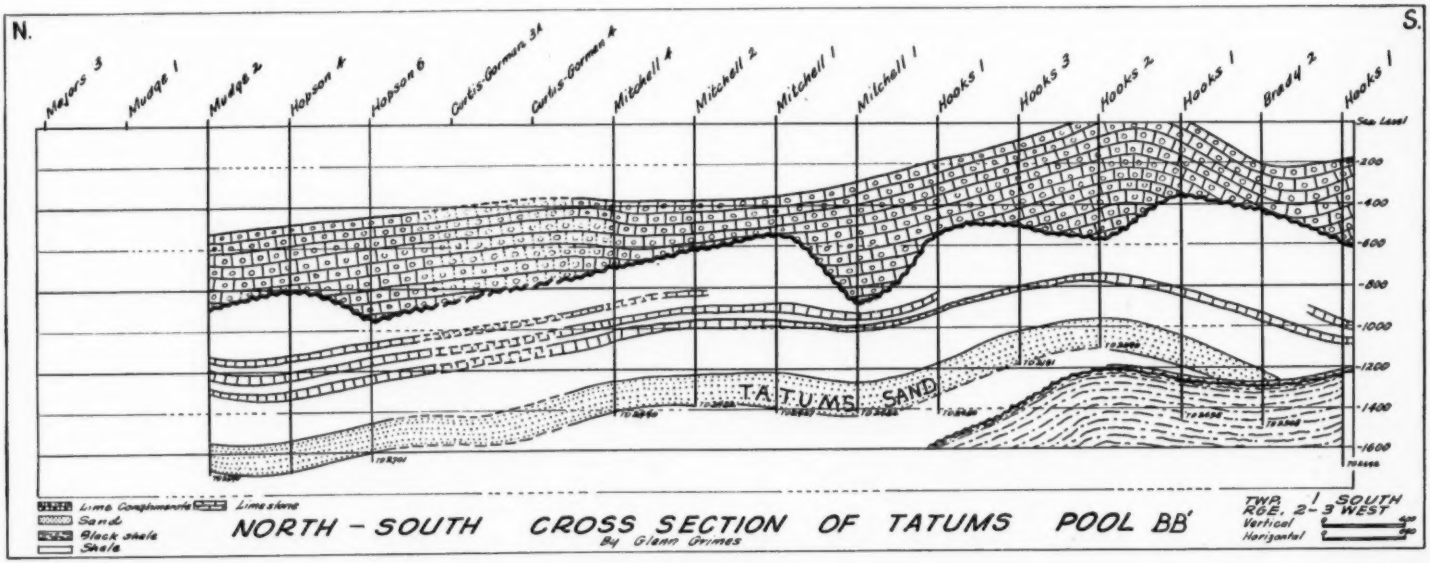

FIG. 2.—North-south cross section of Tatums pool (line *BB'* of Figure 1).

STRATIGRAPHY

The stratigraphy of the Tatums pool in general is similar to the average section in southern Oklahoma, except that a slightly thinner section of Pennsylvanian beds is here encountered. The pool affords a convenient locality for a study of two of the more important unconformities in the subsurface of southern Oklahoma, namely, the Pontotoc and gray Pennsylvanian contact, and the Pennsylvanian and Springer contact.

PERMIAN

Garber sandstone.—The formations at the surface consist of a series of red, rather resistant sandstones interbedded with red or maroon shale, which is probably representative of the base of the Garber sandstone.

Wellington.—The Wellington is represented here by red shales with considerable gypsum locally, with a thickness of about 250 feet.

Asher formation.—Below the Wellington are 200–300 feet of shales which probably belong to the Asher formation, but their identification is not certain.

PERMIAN PONTOTOC

Konawa.—The upper part of the Pontotoc is represented by reddish brown shales and coarse quartz sands of the Konawa formation. The top of this formation is encountered at an average depth of 600 feet and the thickness assigned to this formation is 400 feet. These figures, however, are only tentative.

Stratford.—This formation varies from 300 to 400 feet in thickness. It is marked at the top by coarse quartz sand and at the base by gray, nodular, soft limestone with an average thickness of about 40 feet. This limestone is correlated with the Hart limestone of the Pontotoc terrane. The base of the Hart is tentatively regarded by most writers as the base of the Permian. There is no evidence in the subsurface of the Tatums pool for placing the Pennsylvanian-Permian contact at the base of the Stratford.

PENNSYLVANIAN

PENNSYLVANIAN PONTOTOC

Vanoss formation.—Two hundred feet of shale with a few thin sands and limestones below the base of the Hart limestone is probably representative of the upper part of the Vanoss. One hundred feet to 200 feet of the coarser conglomerates below may be also included, but the base of the Vanoss has not been determined.

Pontotoc conglomerates.—The top of the Pontotoc conglomerate

is found at an average depth of 1,500–1,600 feet, with an average thickness of about 300 feet. In this region the conglomerate is composed essentially of coarse limestone fragments from older formations, especially pre-Devonian. A conspicuous portion of this conglomerate consists of chert fragments of various colors and tints. Another conspicuous feature is a quantity of very coarse, sub-angular to sub-rounded quartz grains. A few broken and distorted fossil fragments can be found, but all are regarded by the writer as transported. There is much glauconite, especially at or near the top of the formation. The cementing material is a thin veneer of soft, white calcite which affords only a very weak bond between the fragments. With intensive study, these conglomerates may be subdivided locally.

Drillers complain of the radical difference in hardness in the various wells. Rock bits are usually required. In the writer's opinion the weak cementing material explains why the holes cave so much while drilling in this formation, and also why it is difficult to get good samples below the conglomerate. The drill may be 200 or 300 feet in the underlying Pennsylvanian, yet the cuttings contain 95–99 per cent of conglomeratic material.

The age of the conglomerates below the Vanoss is doubtful; it may be lower Vanoss, Ada, or Vamoosa.

Vamoosa (?).—Above the gray Pennsylvanian and below the coarse conglomerates is gray, micaceous, nodular, slightly concretionary shale which is probably Vamoosa or younger in age. These shales are present in wells near the center of the south line of Sec. 24, T. 1 S., R. 3 W.

GRAY PENNSYLVANIAN

At the base of the conglomerate and the top of the gray Pennsylvanian is an angular unconformity (Fig. 3). The surface at this unconformity is very uneven, with a relief of as much as 400 feet, and with conspicuous drainage channels.

The Pennsylvanian in this pool varies in thickness from about 300 feet to 2,000 feet or more. It thickens toward the south and west.

The average well encounters about 150 feet of gray, micaceous shale with gray sand streaks below the unconformity. In this shale fossils are plentiful: *Fusulinella*, a short, fat form; a few crinoid stems; and various ostracods, especially *Bairdia*.

Below the gray shale is a 160-foot limestone series of at least three members. The upper member is fairly persistent. Its average thickness is 15–20 feet, and it is identified by its peculiar purplish tint and by its semi-dense crystallization; also, it has at least one ostracod. About 50–60 feet of shale separates this limestone from the second.

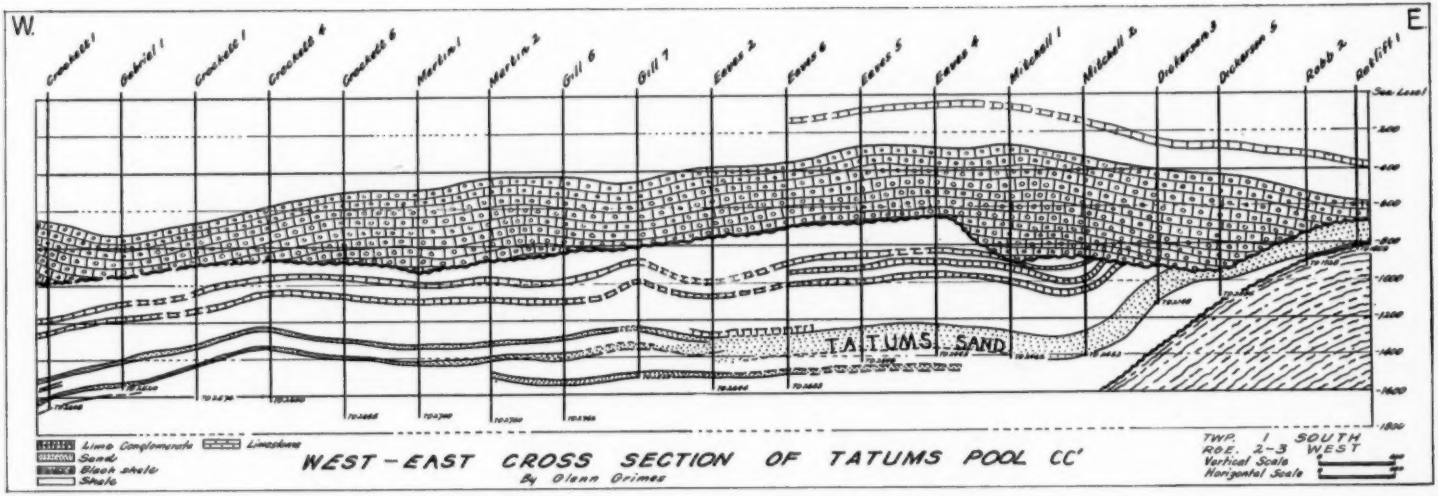

FIG. 3.—West-east cross section of Tatums pool (line *CC'* of Figure 1).

In places a trace of mottled brown and gray shale is found in this shale zone.

The second member is less persistent as a limestone throughout the area, in many places being present as sand with an oil showing. Its average thickness is 25 feet. The lower half is almost everywhere sandy. The limestone is primarily dense and shaly.

The 40 feet of shale which underlies this gray, shaly limestone is the most consistently abundant fossil horizon. At least five different *Bryozoa* have been found, and crinoid stems and *Productus* fragments are abundant. The shale is somewhat conglomeratic.

The lower member of the series consists of about 20 feet of limestone or sand. Usually soft, greenish white limestone with fine, rounded, oblong sand grains is found at the top. Parts of this zone also contain oil.

Below the limestone series are 200–250 feet of gray micaceous shales, somewhat conglomeratic in places and rich in fossils.

Tatums sand.—At the base of the 200-foot shale bed is the Tatums sand of the drillers, found in depths ranging from 1,200 to 2,800 feet in the producing area. Its average thickness in most of the area is 125 feet. The sand is thickest in Section 24 and the eastern part of Section 25. Locally, in Sec. 25, T. 1 S., R. 3 W., it is overlain by fossiliferous limestone conglomerate. It may discontinue as a solid sand and grade into a series of broken sand pay streaks (Fig. 3).

Below the Tatums sand is about 80 feet of shale which is usually gray and micaceous. Except along the east side of the field, there are several hundred feet of gray micaceous shale and sandy shale with a few oil-sand streaks.

MISSISSIPPIAN

The Mississippian is separated from the Pennsylvanian by an unconformity which is regional in scope. The upper member of the Mississippian is the Springer shale. This shale is the lowest formation which has been penetrated in this pool. It is dark gray-to-pure black, uniform in texture, and the general absence of fossils is conspicuous.

STRUCTURAL GEOLOGY

Surface.—The surface geology of this area has not been mapped by the writer, but most of the area can be mapped. The Hart limestone shows definite evidence of folding above the first major unconformity.

Subsurface.—There is definite evidence of folding in Sections 23, 24, and 31, as shown in Figure 1. The dips on the producing sands are as steep as 45°. Minor folds are present in Section 23.

Faulting.—There is some evidence of faulting in the E. ½ of Sec. 23, but it is the writer's opinion that faulting is of very minor significance in the structure of this pool.

Abrupt dips.—It has been noticed in many cores that low dips abruptly increase to almost vertical within a distance of only a few inches. This steep dip may continue for 10–40 feet, then just as suddenly and without any apparent sedimentary change revert to approximately the normal dip of the formation. This condition may be explained by assuming a depositional slope: at intervals, as the overburden became great enough, a small zone would move down the dip and effect a drag on the formations.

There is one apparent exception to this theoretical explanation: a well drilled by the Wirt Franklin Petroleum Corporation in Section 31, at the south end of the field, which had 10 feet of sandstone with a 2-foot chert and crinoid conglomerate at its base, then 2 or 3 feet of black shale, 5 inches of pure dense chert, then several feet of pure black shale with a vertical dip. This vertical dip the writer believes to be definitely the drag in a fault at the top of the Springer shale.

Relation of oil to structure.—There is, as has been mentioned, the main Tatums sand and several lesser sands. Little or nothing is known at present of the producing capacities of these lesser sands. The water line in the Tatums sand is found at a subsea depth of 1,800 feet. There is little or no free gas on the higher part of the structure, the highest well in the field being a 900-barrel oil well in the Tatums sand. In contrast, a well completed in the Tatums sand in the same pool, SW. ¼, SW. ¼, NW. ¼ of Sec. 13, had gas with a spray of oil and was structurally more than 1,000 feet lower than the highest well. The writer suggests that this well is on a separate dome within the main pool, but one in which the Tatums sand was not exposed to erosion. None of the wells produces more than a few barrels of water. There is no evidence of a real water drive. Therefore, it is the opinion of the writer that the propelling force is gas in oil solution. There must be a considerable amount of gas in solution because wells have had an initial production rating as high as 3,000 barrels.

HISTORICAL GEOLOGY

As so far demonstrated by drilling, a Springer mountain existed above sea-level until after the deposition of the Tatums sand. Later deposition covered the Springer within this area. A period of erosion following gray Pennsylvanian time left hills, valleys, outliers, stream beds, et cetera on this land surface, which was later covered by the Pontotoc conglomerate. At the end of Vanoss time, the Arbuckle

Mountains evidently were eroded to a comparatively low elevation, as there is an abrupt change of sediment from conglomerate to shale and sandstone continuing into Garber time.

In Figure 1, the line *AA'*, the eastern extremity of contouring, indicates the location at which the Tatums sand abuts against the Springer land mass (Fig. 2). East of this line, the Springer-Pontotoc interval continues to diminish.

Production in this field extends from a high point on this line of contact at a subsea depth of 100 feet to the water line at a subsea depth of 1,800 feet. Owing to the long nose and terrace across Sections 23 and 24, the producing area there becomes more than 2 miles wide. It is possible that production would exist on a dome covering an area of about 100 acres in Section 23, and on a small dome of about 50 acres in the NE. ¼ of Sec. 24, even without the shore-line condition. Thus, production on about 1,650 acres out of a total of 1,800 acres is due directly to accumulation up the dip against a shore line.

GENERAL PRODUCTION DATA

Proration has been enforced in this pool since August, 1930. At that time the potential was 12,000 barrels, and the allowable was 2,500 barrels.

The present potential (May 1, 1934) is 32,001 barrels from 183 wells. The pool is a Class B pool and is allowed to produce 23 per cent of its potential. Practically all of the wells were flowing wells on completion and many of the wells which have been producing 3 or 4 years are still flowing. However, many wells are now flowing by heads or being pumped. Some companies made a practice of tubing the wells immediately after completion; others did not use tubing until the heading or pumping stage. The original closed-in pressure at the casing head averaged about 600 pounds. At least one company has taken bottom-hole pressures, but this information is not available.

There has been considerable trouble, in general, encountered in pumping these wells, due mainly to the fact that there was a little too much gas, and, as might be expected, considerable experimenting has been done with pumping. Casinghead gas is used to run the gas engines.

The pumping equipment on one property is as follows: one $\frac{2\frac{5}{8}}{8}$-inch plunger on a 2-inch working barrel with a 30-inch stroke, 20–25 strokes per minute. On another, the equipment is as follows: 2½-inch tubing, a 2-inch plunger with a 42-inch stroke, 25–30 strokes per minute. Another company is using successfully the Sullivan pump head which utilizes gas from a compressor plant. This equip-

ment affords a greater pumping capacity and is claimed by the operator to be more efficient than the ordinary methods used to date.

DISCUSSION

C. W. TOMLINSON, Ardmore, Oklahoma (written discussion received, January 28, 1935): Grimes's paper, contour map and cross sections present a clear and in most respects accurate picture of the Tatums pool. However, two or three points are stated as facts which perhaps require further support.

Grimes states that the Springer shale is of Mississippian age. Evidence heretofore presented[3] indicates it to be probably of Pennsylvanian age. Grimes states no new evidence as to age, and his reference to "the general absence of fossils" indicates that he may have none.

Furthermore, it is possible that much of the relatively barren black shale which Grimes calls "Springer" may actually belong in the Dornick Hills formation, which overlies the Springer. From west to east across the field and particularly near the eastern edge, as is well shown by Grimes's Figure 3, successively older beds are in general encountered beneath the basal Pontotoc conglomerates. The wells in which he has identified "Springer" lie near the eastern edge of the field. And yet highly fossiliferous Pennsylvanian strata belonging to the Dornick Hills formation have been encountered in wells still farther east, outside of the producing area indicated on Grimes's map. Two such wells may be cited: Grooms and Lundy's Morris and Luster No. 1, SW., NW., NE., Sec. 19, T. 1 S., R. 2 W., and Murphy and Boggs's Eaves No. 1, SW., SE., SE., Sec. 30, T. 1 S., R. 2 W. The latter was drilled after Grimes's paper was written.

No well in the Tatums field has been drilled into rocks demonstrably older than Pennsylvanian.

Sudden changes in angle of dip, ascribed by Grimes to slippage on a steep depositional slope, are not uncommon in closely folded areas, within wholly conformable sequences. Every drag fold carries them. They have little if any weight as evidence of near-shore deposition.

Two or more distinct sands in the western portion of the field apparently merge eastward into the thick typical "Tatums sand" as shown in Grimes's Figure 3. Such gradations may occur far from shore as well as near it. The extremely sharp eastward termination of the sand may be due to pre-Pontotoc erosional truncation. Its sharpness seems more compatible with that explanation than with the conditions along an original shore line. The steep west dip near the east edge of the field would produce just such a sharp truncation. It would be quite a coincidence if the original shore line of the Tatums sand coincided accurately with the pre-Pontotoc outcrop trace of this horizon—as must be the case under Grimes's explanation.

This point is of particular importance in interpreting the orogenic history of the Arbuckle Mountains, as surface exposures afford little evidence that the western Arbuckle Mountains, west of Washita River, suffered much folding until after Hoxbar time, although the northeastern portion of the mountains and the Criner Hills both afford convincing surface evidence of important orogeny near the close of Springer time.

[3] C. W. Tomlinson, "The Pennsylvanian System in the Ardmore Basin," *Oklahoma Geol. Survey Bull. 46* (1929), pp. 14, 17.

The northern termination of the Tatums sand as shown in Grimes's Figure 2 is less easily explained without recourse to the shore-line hypothesis, for here the terminus does not appear to coincide with the probable pre-Pontotoc outcrop of the same horizon. Nevertheless, the rapid westward thinning and fingering of the Tatums sand horizon across the field shown in Figure 3, not presumed to be related to approach to a western shore line, suggests the possibility that even more abrupt gradation of the sand body into shale might occur at the north edge of the field without the aid of shore-line conditions. Northward dip occurs along the north margin of the field and helps to define it.

The Tatums pay sands thin out west and northwest from the northwest portion of the pool, as well as toward the north in Grimes's cross section *BB'*. There are several dry holes in those directions from the pool which are structurally higher than the lowest producing wells in the pool, but which failed to produce commercially on account of inadequate sand.

GLENN GRIMES: It is not proposed in this paper to question the age of the Springer. Probably Tomlinson is correct, unless the Mississippian is redefined. The black shales in the cross sections are true Springer shales; however, the Murphy Boggs No. 1 Eaves very probably is in Dornick Hills, since the Tatums sand overlaps beds of about Dornick Hills age in a considerable part of the south end of the pool.

Tomlinson states that "it would be quite a coincidence if the original shore line of the Tatums sand coincided accurately with the pre-Pontotoc outcrop trace of this horizon as must be the case under Grimes' explanation." Figure 2 proves definitely that the above condition does not exist over the entire field; the condition shown in Figure 3 is local.

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VOL. 19, NO. 3 (MARCH, 1935), PP. 412-417, 4 FIGS.

GEOLOGICAL NOTES

RESIDUES OF SOME PENNSYLVANIAN LIMESTONES

While searching for various lines of attacking the problem as to the origin and mode of deposition of the Cambridge limestone, H. S. McQueen's studies of insoluble residues came to my attention. He has worked out a method of correlating drill samples by means of their insoluble residues. He states:[1]

> Most striking results have been obtained and indicate that correlations can be made over a wide area with certainty. The study has also suggested that the use of insoluble residues is not limited to correlative purposes only, but may be used with success in other fields of sedimentary research.

In Muskingum County, Ohio, where most of our field work was carried on, the Cambridge limestone varies both in thickness and character. In some places it is flinty and resembles the Brush Creek member, which is found about 40 feet below, while in other places it is light gray and resembles the Ames limestone, which is about 108 feet above the base of the Cambridge. Between the Cambridge and Ames members

> a rather persistent bed of limestone is present in Highland and Salem townships, and local deposits were observed along the horizon as far south as Harrison and Bluerock townships. Owing to the fact that the stratum has excellent thickness and regularity west of Bloomfield in Highland Township, it is called, in this bulletin, the Bloomfield limestone. On the average, its position is about 11 feet above the base of the Cambridge limestone.[2]

Although this member resembles the fossiliferous Cambridge limestone, it can be distinguished from it in the field because it is non-fossiliferous. In drill samples this identification may be more difficult, especially if the samples are poorly taken.

In our work, samples of the Brush Creek, Cambridge, Bloomfield, and Ames limestones were examined, at first with the idea of getting information as to the origin and mode of deposition of the limestones. Later, when striking differences were discovered in the residues of these limestones, they were studied with the idea of using the residues as a means of correlation. McQueen used magnification up to 20 diameters in his study, but in our work we use higher magnification up to 49 diameters because we are interested in the residues as a source of information as to conditions of deposition as well as a means

[1] H. S. McQueen, "Insoluble Residues as a Guide in Stratigraphic Studies," *Missouri Bur. Geol. and Mines, Reprint of Appendix I, Bien. Rept. 1931*, p. 3.

[2] Wilbur Stout, *Geol. Survey of Ohio Bull. 21*, 4th Ser. (1918), p. 242.

of correlation. The material less than 1/16 mm. in diameter was removed and saved for later study.

FIG. 1.—Residue of Brush Creek limestone. Finely crystalline siliceous material showing elongate pores. ×17.

In that part of Muskingum County in which our field work was conducted, the Brush Creek is represented by a dark fossiliferous shale, but in Lawrence and Gallia counties it is a well developed limestone. The residue consists of aggregates of granular, finely crystalline siliceous material which seems to be quartz coated with an isotropic siliceous mineral, possibly opal. These aggregates contain small, elongate openings or pores which are circular in cross section. Some of these pores are grooved, while others have a central core. These

FIG. 2.—Porous aggregates of opaline silica characteristic of Cambridge limestone residues. ×17.

characters lead us to conclude that they were occupied by calcareous fossils. In some samples dark, slag-like masses were found, which probably represent ferruginous impurities.

Nearly 40 feet above the base of Brush Creek, in Muskingum County, is the Cambridge limestone, some of the characteristics of which have been suggested earlier in this article. The insoluble residue contains porous aggregates of opaline silica which resemble finely vesicular pumice. These aggregates also show pores similar to those of Brush Creek and in addition some clear siliceous rods of size and shape comparable with the size and shape of the pores found in the aggregates.

FIG. 3.—Very fine powdery aggregates of siliceous material resulting from digestion of Bloomfield limestone. ×17.

The residues of the Cambridge limestone from Gallia and Lawrence counties show the same general characteristics as those from Muskingum County, the outstanding characteristic being the vesicular pumice-like aggregates of siliceous material. In some samples from the southern part of the state, sub-angular particles of a clear mineral, perhaps fluorite, were found. Aggregates of pyrite, in some cases crystallized in pyritohedrons, and also pieces of a dark, opaque mineral were found. These are minor constituents and are not characteristic of the most of the Cambridge limestone samples studied. It is notable, however, that the same general characteristics exist in the residues of the same member in localities as widely separated as those studied.

In Highland and Salem townships of Muskingum County, the Bloomfield limestone is present about 11 feet above the Cambridge

member. This rock is hard and dense and not easily weathered. The insoluble residue of this limestone is made up of aggregates of very fine, powdery, siliceous material which are easily broken up into a fine powder. Some of these aggregates show openings similar to those described in the Brush Creek and Cambridge residues. Dark, slag-like particles which are not characteristic of all the samples, but possibly represent local differences or impurities, sometimes occur. Some samples contain rod-like bodies similar to those found in the Cambridge.

About 108 feet above the Cambridge limestone is one of the most

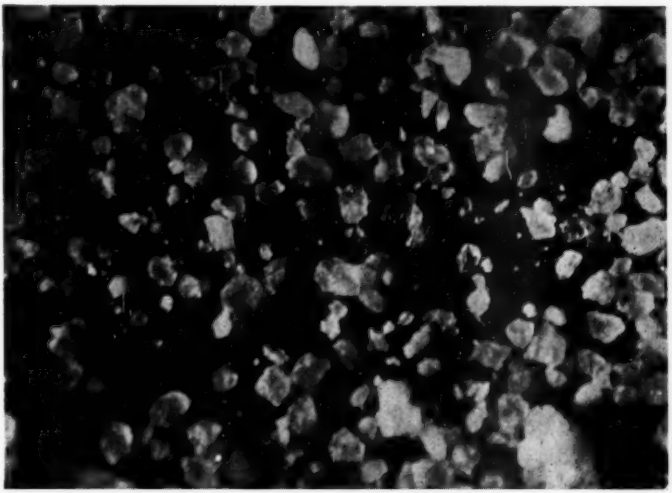

FIG. 4.—Residue of Ames limestone showing well rounded, pitted particles of clear quartz. ×17.

important horizons in the Conemaugh formation because of its service as a stratigraphic key. This is the Ames limestone. Condit says:

> There are certain lithologic characteristics which are remarkably constant and they alone enable one to distinguish it from other limestones. They are briefly summarized as follows: It is a gray or greenish-gray limestone, ordinarily in a single bed 1 to 3 feet thick. Fossils are abundant, especially crinoids, which stand out in relief on the weathered surface. The rock on fracture shows a more or less granular, crystalline texture, due to cleavage faces of calcite, and is frequently spotted with minute, glauconitic grains.[3]

The insoluble residue is a sand composed largely of well rounded particles of clear quartz, some of which are pitted as if wind blown.

[3] D. Dale Condit, *Geol. Survey of Ohio Bull. 17*, 4th Ser. (1912), p. 29.

Some of the sand grains are sub-angular. Numerous glauconite particles are found which are apparently of organic origin, for some are foraminifer-like while others are porous, spongy masses. In some samples dark, slag-like masses are found which are not characteristic of all samples.

Thus we see that the insoluble residues of at least four of the Conemaugh limestones in certain sections of Ohio are sufficiently characteristic to enable us to correlate them when found in small particles such as drill samples. Minor differences have been noted in the individual constituents, but the general features of the residues examined are the same for the same member in the area studied.

McQueen states that his detailed studies have been restricted to the Cambrian and Lower Ordovician, but that enough work has been done on the Silurian, Devonian, Mississippian, and Pennsylvanian of his state to indicate that this method of study can be used. There is little doubt that if his method of study were more widely tried, and the results of such studies recorded, they would prove useful in many cases in correlating well samples with considerable certainty.

ROBERT H. MITCHELL

MUSKINGUM COLLEGE
NEW CONCORD, OHIO
November, 1934

STRATIGRAPHICAL AND STRUCTURAL STUDIES IN MINING REGIONS

(New Fields for the Oil Geologist)

The influence of structure on the localization of ore bodies was discussed several years ago by Newhouse,[1] who made the statement that epigenetic ore districts on folded rocks are nearly always on the flanks or crest of an anticlinal fold. New evidence in support of this view is forthcoming from detailed mapping in various regions, particularly Australia. In certain instances, geological conditions are such that the field procedure in mapping is not greatly different from that in oil regions such as California. Those well qualified for structural and stratigraphical studies under such conditions can put their training to good use for field mapping of certain types of ore occurrences.

Gold mineralization is exceptionally widespread over large areas in Western Australia. This country includes the famous old mining camps—Kalgoorlie, Coolgardie, Menzies, and other localities northward and westward for hundreds of miles. From results obtained of late, there appears to be a definite, though as yet imperfectly understood, structural control of the localization of the ore deposits. It is

[1] W. H. Newhouse, "Some Relations of Ore Deposits to Folded Rocks," *Amer. Inst. Min. Met. Eng. Tech. Pub.* 422 (February, 1931), pp. 1–25.

only after a thorough knowledge of the stratigraphic succession that the structure can be worked out and relation of ore bodies to structure determined. In pursuance of the work, air photography has been extended over large areas, and regional mapping is in progress under supervision of a geologist trained in oil-field methods as practiced in California.

Earlier published data are largely misleading. Reconnaissance surveys of parts of the region, by the State Geological Survey, represent the rocks as largely greenstones (regarded as intrusive rocks) and granite. With recent studies it becomes evident that the greenstones are composed of bedded tuffs and lava flows, with minor amounts of intrusions, and of sedimentary strata which, though greatly altered, still largely preserve their characteristics, and that even some of the gneissic granites are altered sedimentary deposits, though heretofore regarded as wholly of igneous origin.

The gold deposits of the Rand, South Africa, present a somewhat different problem, though also requiring a study of stratigraphy and structure. Auriferous conglomerates lie in the midst of a great pre-Cambrian sedimentary system, the Witwatersrand, 12,000–24,000 feet thick. Outcrops are good in much of the Central Rand, and exploratory work has been comparatively simple since the "Main Reef" and associated strata of east-west strike crop out more or less continuously for nearly 40 miles. Most of the mining activity is in this portion, and the deeper workings have been carried down dip to a vertical depth exceeding 8,000 feet. Since the ore bodies are more or less localized in definite stratigraphic units, the guidance required in exploration of outlying districts is to be had mainly through studies of sedimentation and structure. Reinecke has made a beginning at such work.[2]

Eastward from the Central Rand the older rocks are extensively covered by the flat-lying Karoo strata (late Paleozoic). Though there has been little effort at exploration, it is surmised that this area may be broadly synclinal and underlain by the Witwatersrand. The magnetometer is used for guidance, since it is known that certain shaly strata immediately beneath the conglomerates of the productive area on the west are rich in magnetite. Following the information supplied by this and other geophysical methods, the area is being tested by core-drilling. Correlation by the heavy-mineral method should prove useful where stratigraphic relationships are in doubt, but so far as known this method has not been applied on the Rand.

D. DALE CONDIT

SYDNEY, AUSTRALIA,
January 8, 1935

[2] L. Reinecke, "Origin of the Witwatersrand System," *Trans. Geol. Soc. South Africa*, Vol. 33 (1930), pp. 111–33.

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REVIEWS AND NEW PUBLICATIONS

A Laboratory Manual of Physical and Historical Geology. By KIRTLEY F. MATHER and CHALMER J. ROY. XIII and 302 pp., 46 figs., 20 pls., 1 map. Paper. 8.375×10.75 inches. D. Appleton-Century Company, New York (1934).

This manual, as stated by the authors in the preface, "is intended specifically to be used in connection with the textbook entitled 'Earth History' by L. C. Snider." The exercises, of which there are twenty, are designed for three-hour laboratory periods.

Twelve exercises are devoted to physical geology. The first six treat of rock-forming minerals, economic minerals, rocks, and the weathering of igneous rocks. The remaining exercises in the group deal with topographic maps, running water, ground water and wind, mountain glaciers and continental ice sheets, waves and currents, and land forms. Preceding the assignment of each exercise is an excellent and well illustrated summary of the subject with which the student is to deal. From a statement made in the preface the reviewer understands that these summaries are included to supplement material which is not adequately treated by Snider. All of the exercises other than those on rocks and minerals are based on United States Geological Survey quadrangle maps, which have been well selected for the exercises in which they are used.

The last eight exercises in the manual are devoted to historical geology, which is treated on a regional basis instead of by periods. The first one of this group is designed to acquaint the student with the information available in the folios of the United States Geological Survey, which are used very extensively in this portion of the manual. The succeeding exercise is devoted to fossils, and the remaining six treat the geologic history of the Appalachian mountain system, the Interior Lowlands, Interior Highlands and High Plains, the Rocky mountain system and Colorado Plateau, the Great Basin and the Pacific Border mountains, the glaciated areas of the United States, and the Canadian Shield. The geologic folios in these exercises are supplemented by many structure sections, numerous geologic maps, and two columnar sections.

The manual contains an "Outline of the Lectures Designed to Serve as an Introduction to Geology (with References and Assigned Readings)" and a well chosen "List of Reference Books." The appendices are as follows: "Key to the Identification of Common Minerals," "Geological Chronology," "Classification of the Vertebrates," and "Laboratory Equipment and Supplies." The manual is punched for insertion in a loose-leaf binder, and pages for laboratory work, which are perforated for detachment, follow each exercise.

The use of numerous folios which have been out of print for a considerable length of time may to some extent limit the adoption of this manual.

The manual, and particularly the clear, direct questions which treat of the fundamentals of the subject, reflect care, thought, and experience in laboratory teaching.

A. N. MURRAY

TULSA, OKLAHOMA
January 25, 1935

RECENT PUBLICATIONS

ARKANSAS

Oil and Gas Geology of the Gulf Coastal Plain in Arkansas, by W. C. Spooner. With a chapter on "Upper Cretaceous Ostracoda," by Merle C. Israelsky. Published from manuscript obtained from the *Arkansas Geological Survey*, and referred to as *Bulletin 2*, but privately printed by Parke-Harper Printing Company, Little Rock, Arkansas (1935), who will accept orders at $3.80 per copy. 516 pp., 95 figs., 22 pls., 57 tables. Size 6×9 inches. Blue cloth, stamped in gold.

FRANCE

Compte Rendus des Séances du Groupe des Géologues Pétroliers de Strasbourg (Publications of the Meetings of the Society of Petroleum Geologists of Strasbourg), Vol. 2, Nos. 3–4 (1933–34), 27 pp. In French. Contains 4 articles: "The 'Waterwitch,' a Method of Locating Water in Wells," by A. Lochkareff, 3 figs.; "Development of Drilling Methods," by A Comet; "An Exploitable Oil Zone in the Keuper of the Pechelbronn Basin," by R. Schnaebele, 3 figs.; and "Geology of the Malvesy Sulphur Deposit (Narbonne Basin) and Associated Bituminous Rocks," by D. Schneegans. Annual subscription, 25 francs for 6 numbers, M. R. Schnaebele, treasurer, Merckwiller-Pechelbronn (Bas-Rhin).

"La prospection du pétrole dans les Etats du Levant sous mandat français" (Petroleum Prospects in Eastern Mediterranean Countries under French Mandate), by L. Dubertret. La Chronique des Mines Coloniales (13, Rue de Bourgogne, Paris, 73), Vol. 4, No. 34 (January 1, 1935), pp. 5–9, 1 map.

GENERAL

"Croncrumcompasses. Compasses with a Nonius for Measurement (0.01 mm.) with Changeable Points of Various Form," by V. A. Teriaeff. *Problems of Soviet Geology* (Moscow), No. 10 (1934), pp. 166–73; 6 figs. Description of author's invention for measurements in paleontology, especially useful in exact measurements for determination of species.

Engineering Surveys, by Harry Rubey. A book in the *Engineering Science Series*, edited by E. R. Hedrick. 230 pp., 250 diagrams and photographs, 101 pp. of tables. Size 5×7.75 inches. Flexible green cover, rounded corners. The Macmillan Company, 60 Fifth Avenue, New York (1935). Price, $3.00.

"Is the 'Roots-of-Mountains' Concept Dead?" by Chester R. Longwell. *Amer. Jour. Sci.* (New Haven, Connecticut), 5th Ser., Vol. 29, No. 170 (February, 1935), pp. 81–92; 2 figs.

"Basal Relations of Galena Dolomite, Upper Mississippi Valley, Lead and Zinc District," by G. Marshall Kay and Gordon I. Atwater. *Ibid.*, pp. 98–111; 4 figs.

"Die Gebirgsumrahmung des nordamerikanischen Kontinents" (The Mountain Frame-Work of the North American Continent), by Rudolf Schottenloher. *Mitteilungen der Geographischen Gesellschaft* (Trans. Geographical Society, Vienna), Vol. 77, Nos. 7–9 (1934), pp. 129–45; 1 map.

"Bibliographic Index of Paleozoic Ostracoda," by R. S. Bassler and Betty Kellett. *Geol. Soc. America Spec. Paper 1* (1934). 500 pp., 24 figs. 6.375×9.75 inches.

"Flaws and Tear Faults," by Elwyn L. Perry. *Amer Jour. Sci.* (February, 1935), pp. 112–24; 2 figs.

"Correlations of the More Important Marine Permian Sequences," by Charles Schuchert. *Bull. Geol. Soc. America*, Vol. 46. No. 1 (January 31, 1935), pp. 1–45; 1 pl., 1 fig., 6 tables.

"Tertiary Grasses and Other Prairie Vegetation from High Plains of North America," by Maxim K. Elias. *Amer Jour. Sci.*, Vol. 29, No. 169 (January, 1935), pp. 24–33; 1 pl.

GEOPHYSICS

"An Instance of Abnormal Magnetic Polarization in South Africa, Together with a Graphic Method for Determining Effects of Magnetic Pole Distribution," by F. Bahnemann. *Amer. Inst. Min. Met. Eng. Contribution 79*, Class L. Geophysical Prospecting (New York meeting, February, 1935). 12 pp., 11 figs.

"Observations on Compensated Magnetometer Systems," by Mark C. Malamphy and Irnack C. do Amaral. *Ibid., 80.* 13 pp., 5 figs.

"Méthodes pratiques de travail en prospection géophysique" (Practical Methods in Geophysical Prospecting), by C. L. Alexanian. *Annales Combustibles Liquides* (Paris, November-December, 1934), pp. 995–1011.

The following publications have been prepared by the U. S. Coast and Geodetic Survey and may be purchased from the Superintendent of Public Documents, Government Printing Office, Washington, D. C.

"Investigations of Gravity and Isostasy," *Spec. Pub. 40.* $0.60.

"Modern Methods for Measuring the Intensity of Gravity," *Spec. Pub. 69.* $0.15.

"Isostatic Investigations and Data for Gravity Stations in the United States Established Since 1915," *Spec. Pub. 99.* $0.25.

"A Gravimetric Test of the 'Roots of Mountains' Theory," *Serial No. 291.* $0.05.

"Use of the Gravity Pendulum as a Timepiece," *Serial No. 356.* $0.05.

"Isostatic Condition of the United States as Indicated by Groups of Gravity Stations," *Serial No. 366.* $0.05.

GERMANY

"Die deutsche Erdölförderung 1933/34" (German Petroleum Development in 1933–34), by Wilhelm Georg Simon. *Kali, Verwandte Salze und Erdöl* (Berlin), Vol. 29, No. 2 (January 15, 1935), pp. 15–20; 8 figs.

KANSAS

"Acid Treatment in Kansas Fields," by L. C. Morgan. *Petrol Eng.* (Dallas, Texas, December, 1934), pp. 48–50; 4 illus.

MISSOURI

"Oil and Gas Possibilities of the Savannah Area, Andrew County, Missouri," by Frank C. Greene. Appendix II of *58th Biennial Rept. State Geologist, Missouri Geol. Survey* (Rolla, 1935). 26 pp., 2 pls.

"Oil and Gas Developments in Missouri in 1933–34," by Frank C. Greene. Appendix III of *58th Bienn. Rept. State Geologist, Missouri Geol. Survey.* 21 pp., 3 figs.

MONTANA-NORTH DAKOTA

Cedar Creek Anticline, Montana-North Dakota, by C. E. Dobbin, C. E. Erdmann, R. M. Larsen, *et al.* A new map of the areal and structural geology of the Cedar Creek, or Baker-Glendive, anticline, by the U. S. Geological Survey. Scale, approximately 1 inch equals 1 mile. Limited photolithograph edition for free distribution. U. S. Geological Survey, Washington, D. C.; 523 Customhouse, Denver, Colorado; 305 Federal Building, Casper, Wyoming; 305 Federal Building, Billings, Montana.

NEBRASKA

"Miocene and Pliocene Mammalian Faunas, Valentine, Nebraska," by R. A. Stirton and Paul O. McGrew. *Amer. Jour. Sci.* (February, 1935), pp. 125–32; 3 figs.

PENNSYLVANIA

"Hypothyridina Venustula (Hall) in Pennsylvania," by Bradford Willard. *Amer Jour. Sci.*, Vol. 29, No. 170 (February, 1935), pp. 93–97; 1 fig.

"What is 'Pocono'?" by George Halcott Chadwick. *Ibid.*, pp. 133–43; 1 fig.

POLAND

"La corrélation des horizons pétrolifères dans le grès de Boryslaw à Tustanowice-l'Est" (Correlation of Petroliferous Horizons in the Sandstone of Boryslaw in Eastern Tustanowice), by O. V. Wysznski. *Carpathian Geol. Survey Bull. 24* (Boryslaw, Poland, 1934). 22 pp., 10 illus. In Polish and French.

RUSSIA

"Études géophysiques par les méthodes électriques en U.R.S.S." (Geophysical Studies by Electrical Methods in Union of Socialistic Soviet Republics), by C. and M. Schlumberger and P. Charrin. *Rev. Petrol.* (Paris), No. 614 (January 19, 1935), pp. 77–83; 5 figs. First installment.

TEXAS

"Tabulated Analyses of Texas Crude Oils," by Gustav Wade. *U. S. Bur. Mines R. I. 3252* (December, 1934). Mimeographed, 40 pp., 1 fig.

WEST INDIES

"Some Fossil Corals from the West Indies," by John W. Wells. *Proc. U. S. Nat. Mus.*, Vol. 83, No. 2975 (1934), pp. 71–110, pls. 2–5.

WYOMING

"Structural Detail Near Western Border of Thrust Sheets, North of Shoshone River, Wyoming," by Martin M. Sheets. *Amer. Jour. Sci.* (February, 1935), pp. 144–50; 1 fig.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 19, NO. 3 (MARCH, 1935), PP. 422-467

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to J. P. D. Hull, business manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Eugene Edward Brossard, Ciudad Bolivar, Venezuela, S. A.
Philip Andrews, C. M. Crebbs, P. E. Nolan
Ralph E. Knipe, Marshall, Ill.
E. R. Brockway, C. L. Moody, C. R. Steinberger
Oramel Ainsworth Seager, Duncan, Okla.
Glenn D. Hawkins, Frank Gouin, Gerald C. Maddox
Hans Karl Stauffer, Maracaibo, Venezuela, S. A.
E. A. L. Gevaerts, J. Dufour, P. E. Nolan
Kirk Schroder White, Tulsa, Okla.
George D. Morgan, George S. Buchanan, D. C. Nufer
Wilberforce Hurlbut Young, Jr., Bradford, Pa.
F. E. Eckert, K. B. Nowels, W. T. Thom, Jr.

FOR ASSOCIATE MEMBERSHIP

Kenneth Stewart Cronin, Houston, Tex.
John S. Cruse, Jr., R. M. Beatty, Donald M. Davis
George L. Lockett, Maracaibo, Venezuela, S. A.
Chester A. Baird, John G. Douglas, P. E. Nolan
William Ernest McHugh, Wichita, Kan.
W. A. Ver Wiebe, John F. Kinkel, Howard S. Bryant
James Dale Perryman, Golden, Colo.
Dart Wantland, F. M. Van Tuyl, J. Harlan Johnson
Theodore Leland Tapp, Maracaibo, Venezuela, S. A.
John G. Douglas, Chester A. Baird, P. E. Nolan
William Ward West, Wichita, Kan.
W. A. Ver Wiebe, E. A. Wyman, Howard S. Bryant

FOR TRANSFER TO ACTIVE MEMBERSHIP

Jo Pat Black, Houston, Tex.
C. A. Russell, W. F. Henniger, Paul Weaver
Raymond Russell Moody, Tulsa, Okla.
Anthony Folger, W. R. Longmire, George H. Norton

FINANCIAL STATEMENT, 1934

To the EXECUTIVE COMMITTEE,

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, TULSA, OKLAHOMA.

We have examined the accounting records of THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS as at December 31, 1934, from which the following statements have been prepared:

Exhibit

- *A* Statement of Financial Condition as at December 31, 1934
- *B* Statement of Income for the year ended December 31, 1934
- *C* Statement of Income from Publications for the year ended December 31, 1934
- *D* Statement of General and Administrative Expenses for the year ended December 31, 1934

Cash in Banks was confirmed by the depositaries; Reserves of $1,503.32 have been provided for Accounts Receivable from Members and Others; Inventories of Printed Matter are at current appraised values and represent the supply of publications to meet anticipated requirements; Investments were verified by inspection or confirmation from the depositaries and are stated at the lower of cost or market.

The net profit for the year ended December 31, 1934, of $13,119.11 includes Extraordinary Items of $7,258.43 representing adjustment of Bond Investment in the amount of $4,776.06 and Recovery of Delinquent Dues previously charged off of $2,509.68 less loss on sale of bonds amounting to $27.31. It is the procedure of the Association to reflect the Investment in Bonds at the lower of cost or market and in prior periods the book value has been reduced by reserves provided for market fluctuation. During the year ended December 31, 1934, there was a material increase in the market value of certain bonds over their December 31, 1933, market value. The reserves previously provided were therefore adjusted as of December 31, 1934, in the amount of $4,776.06, which amount is reflected as an Extraordinary Item in the Statement of Income—Exhibit *B*. During the year ended December 31, 1934, the Association collected or reinstated membership dues for prior years, which had previously been charged off, in the amount of $2,509.68. This amount is also reflected in Exhibit *B* as an Extraordinary Item.

Subject to the foregoing, in our opinion, the accompanying statement of Financial Condition and related Statements of Income and Expenses, respectively, correctly reflect the financial condition of THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS at December 31, 1934, and the results of its operations for the year ended on that date.

(Signed) ARTHUR YOUNG & CO.
Accountants and Auditors

TULSA, OKLAHOMA
January 14, 1935

EXHIBIT A

STATEMENT OF FINANCIAL CONDITION AS AT DECEMBER 31, 1934

ASSETS	Total	General Fund	Publication Fund	Research Fund
CURRENT ASSETS:				
Cash in Banks:				
The First National Bank and Trust Company, Tulsa, Oklahoma	$10,688.53	$ 6,818.19	$ 3,870.34	$ —
National Bank of Commerce, Tulsa, Oklahoma	334.58	334.58	—	—
TOTAL CASH IN BANKS	$11,023.11	$ 7,152.77	$ 3,870.34	$ —
Accounts Receivable:				
Members (Less Reserve for Doubtful Accounts $1,267.00)	$ 549.50	$ 549.50	$ —	$ —
Advertising (Less Reserve for Doubtful Accounts $236.32)	195.25	195.25	—	—
Printed Matter	732.45	565.80	166.65	—
Miscellaneous	84.30	84.30	—	—
TOTAL ACCOUNTS RECEIVABLE	$ 1,561.50	$ 1,394.85	$ 166.65	$ —
Accrued Interest Receivable (Less Reserve $1,159.99)	$ 615.95	$ 424.11	$ 167.93	$ 23.91
Inventory—Printed Matter:				
Bulletins, Etc.				
Cost	$38,782.94	$37,524.00	$ 1,258.94	$ —
Less: Reserve therefor	20,574.40	20,574.40	—	—
Net Value	$18,208.54	$16,949.60	$ 1,258.94	$ —
Special Publications in Process:				
Geology of Natural Gas	4,360.83	—	4,360.83	—
Gulf Coast Volume	2.88	—	2.88	—
	$22,572.25	$16,949.60	$ 5,622.65	$ —
TOTAL CURRENT ASSETS	$35,772.81	$25,021.33	$ 9,827.57	$ 23.91
INVESTMENTS:				
At Lower of Cost or Market				
Cost	$57,047.24	$39,259.78	$16,374.91	$1,412.55
Less: Reserve	8,868.04	5,517.32	3,123.22	227.50
TOTAL INVESTMENTS	$48,179.20	$33,742.46	$13,251.69	$1,185.05
FIXED ASSETS:				
Furniture and Fixtures	$ 3,538.92	$ 3,538.92	$ —	$ —
Less: Reserve for Depreciation	2,142.46	2,142.46	—	—
TOTAL FIXED ASSETS	$ 1,396.46	$ 1,396.46	$ —	$ —
PREPAID AND DEFERRED CHARGES:				
Paper Stock on Hand at Printers	$ 18.16	$ 18.16	$ —	$ —
Prepaid Insurance	41.57	41.57	—	—
TOTAL P. AND D. CHARGES	$ 59.73	$ 59.73	$ —	$ —
TOTAL ASSETS	$85,408.20	$61,119.98	$23,079.26	$1,208.96

LIABILITIES AND SURPLUS	Total	General Fund	Publication Fund	Research Fund
CURRENT LIABILITIES:				
Accounts Payable	$ 1,543.58	$ 1,543.58	$ —	$ —
Accrued Printers Costs—Geology of Natural Gas	2,708.23	—	2,708.23	—
TOTAL CURRENT LIABILITIES	$ 4,251.81	$ 1,543.58	$ 2,708.23	$ —
DEFERRED INCOME:				
Active Membership Dues—1935	$ 2,887.80	$ 2,887.80	$ —	$ —
Associate Membership Dues—1935	414.00	414.00	—	—
1935 Subscriptions to Bulletins	1,909.01	1,909.01	—	—
1936 Subscriptions to Bulletins	13.90	13.90	—	—
Subscriptions to Geology of Natural Gas	220.50	—	220.50	—
Subscriptions to Bound Volume XVIII	354.00	354.00	—	—
Prepaid Advertising	418.00	418.00	—	—
TOTAL DEFERRED INCOME	$ 6,217.21	$ 5,996.71	$ 220.50	$ —
SIDNEY POWERS MEMORIAL FUND	$ 167.50	$ 167.50	$ —	$ —
SURPLUS:				
Balance—December 31, 1933	$61,652.57	$42,753.05	$17,819.08	$1,080.44
Net Profit for the year ended December 31, 1934—Exhibit *B*	13,119.11	10,659.14	2,331.45	128.52
Balance—December 31, 1934	$74,771.68	$53,412.19	$20,150.53	$1,208.96
TOTAL LIABILITIES AND SURPLUS	$85,408.20	$61,119.98	$23,079.26	$1,208.96

EXHIBIT B

STATEMENT OF INCOME FOR THE YEAR ENDED DECEMBER 31, 1934

TOTAL ASSETS	$85,408.20	$61,119.98	$23,079.26	$1,208.96

TOTAL LIABILITIES AND SURPLUS	$85,408.20	$61,119.98	$23,079.26	$1,208.96

EXHIBIT B
STATEMENT OF INCOME FOR THE YEAR ENDED DECEMBER 31, 1934

	Members Annual Dues			*General Fund*	*Publication Fund*	*Research Fund*	*Total*
OPERATING INCOME:							
DUES:							
Active Membership	1,456	$12.00		$17,472.00	$ —	$ —	$17,472.00
Associate Membership	39	12.00	$ 468.00		$ —	$ —	468.00
Associate Membership	272	8.00	2,176.00		—	—	2,176.00
	311			2,644.00	—	—	2,644.00
	1,767			$20,116.00	$ —	$ —	$20,116.00
Deduct: Transfer to Income from Bulletins							
Active Membership	1,456	$ 6.00	$8,736.00		$ —	$ —	$8,736.00
Associate Membership	311	6.00	1,866.00		—	—	1,866.00
	1,767			10,602.00	—	—	10,602.00
				$ 9,514.00	$ —	$ —	$ 9,514.00
PUBLICATIONS—Net Income Exhibit *C*				3,374.49	725.39	—	4,099.88
CONVENTION RECEIPTS (Net)				*—91.39*	—	—	*—91.39*
TOTAL OPERATING INCOME				$12,797.10	$ 725.39	$ —	$13,522.49
GENERAL AND ADMINISTRATIVE EXPENSES—							
Exhibit *D*				9,962.53	—	—	9,962.53
NET OPERATING INCOME				$ 2,834.57	$ 725.39	$ —	$ 3,559.96
NON-OPERATING INCOME:							
Interest on Investments			$1,579.83		$ 572.19	$61.02	$2,213.04
Miscellaneous			82.39		5.29	—	87.68
				1,662.22	577.48	61.02	2,300.72
NET INCOME BEFORE EXTRAORDINARY ITEMS				$ 4,496.79	$1,302.87	$ 61.02	$ 5,860.68
EXTRAORDINARY ITEMS:							
Adjustment of Bond Investment to Lower of Cost or Market			$3,679.98		$1,028.58	$67.50	$4,776.06
Recovery of Delinquent Dues previously Charged Off			2,509.68		—	—	2,509.68
Loss on Sale of Bonds, etc.			*—27.31*		—	—	*—27.31*
				6,162.35	1,028.58	67.50	7,258.43
Net Profit—Transferred to Surplus Exhibit *A*				$10,659.14	$2,331.45	$128.52	$13,119.11

EXHIBIT C

STATEMENT OF INCOME FROM PUBLICATIONS FOR THE YEAR ENDED DECEMBER 31, 1934

	General Fund—Bulletins		*Publication Fund*		*Total*	
OPERATING INCOME:						
Dues Transfered—						
Active Membership	$ 8,736.00		$ —		$ 8,736.00	
Associate Membership	1,866.00		—		1,866.00	
		$10,602.00		$ —		$10,602.00
Sale of Bulletins—						
Subscriptions	$ 3,414.83		$ —		$ 3,414.83	
Advertising	2,524.90		—		2,524.90	
		5,939.73		—		5,939.73
		$16,541.73		$ —		$16,541.73
Sale of Bound Volumes and Special Publications—						
Bound Volumes	$ 1,677.24		$ —		$ 1,677.24	
Back Numbers	391.44		—		391.44	
Indexes	7.70		—		7.70	
Alberta Symposium	13.99		—		13.99	
Structure Volume I	—		411.28		411.28	
Structure Volume II	425.88		—		425.88	
Geology of California	—		946.35		946.35	
Problems of Petroleum Geology	5,181.26		—		5,181.26	
		7,697.51		1,357.63		9,055.14
TOTAL OPERATING INCOME		$24,239.24		$1,357.63		$25,596.87
OPERATING COSTS:						
Manager's Salary (Proportion)	$ 2,500.00		$ —		$ 2,500.00	
Editorial Salary	3,281.20		—		3,281.20	
Cost of Printing Bulletins (Including paper stock furnished by the Association $1,549.27)	8,589.11		—		8,589.11	
Cost of Engraving	1,454.43		—		1,454.43	
Cost of Printing Separates	276.92		—		276.92	
Stencil Corrections and Mailing	138.20		—		138.20	
Binding Volume XVI (Additional Copies)	94.35		—		94.35	
Binding Volume XVII	327.77		—		327.77	
Binding Extra Copies 1932 and 1933 Bulletins (Paper)	82.23		—		82.23	
Problems of Petroleum Geology—Printing and Binding	6,270.01		—		6,270.01	
Copyright Fees	24.00		—		24.00	
Bulletin Mailing and Express	714.57		—		714.57	
Other Publications Freight and Express	574.96		31.52		606.48	
Discount on Publications	35.20		20.95		56.15	
Purchase of Back Numbers	3.50		—		3.50	
Miscellaneous Bulletin Expense	26.91		—		26.91	
	$24,393.36		$ 52.47		$24,445.83	
Deduct: Inventory Increase—*Decrease*	3,528.61		−579.77		2,948.84	
Total Cost of Publications Sold		20,864.75		632.24		21,496.99
Net Income from Publications—Transferred to Exhibit *B*		$ 3,374.49		$ 725.39		$ 4,099.88

EXHIBIT D

STATEMENT OF GENERAL AND ADMINISTRATIVE EXPENSES FOR THE YEAR ENDED DECEMBER 31, 1934

Manager's Salary (Proportion)	$1,670.83
Clerical Salaries	4,800.29
Office Rent	325.00
Telephone and Telegraph	297.78
Postage—General	991.53
Printing and Stationery	147.57
Office Supplies and Expenses	389.61
Insurance	92.50
Audit Fee	450.00
Freight and Express	48.00
Tax on Checks	9.14
Exchange and Refunds	7.99
Donations to Society of Economic Paleontologists and Mineralogists	354.00
Wichita Meeting	3.00
Miscellaneous	41.92
Depreciation of Furniture and Fixtures	333.37
Total Transferred to Exhibit *B*	$9,962.53

FINANCIAL STATEMENT, GEOPHYSICS DIVISION, 1934

MR. E. E. ROSAIRE, PRESIDENT,
SOCIETY OF PETROLEUM GEOPHYSICISTS,
HOUSTON, TEXAS

Dear Sir:

Pursuant to instructions received, we have made an audit of the financial transactions of B. HUBBARD, TREASURER, SOCIETY OF PETROLEUM GEOPHYSICISTS, for the period from March 24, 1934, to December 31, 1934, inclusive.

Our examination did not embrace a confirmation by correspondence of dues from members and delinquents in respect thereto.

Exhibit A [not here printed] is a statement of dues receivable from March 24, 1934, to December 31, 1934, inclusive. The list of members and "back dues" are taken from the records of the Treasurer. Upon inquiry, we were advised there was no former report or list of delinquents with which these records could be reconciled.

Summaries of the "Dues Receivable" account and cash transactions are presented below:

DUES RECEIVABLE:		
Back dues		$ 220.00
Current dues	$870.00	
Less—paid to former Treasurer	5.00	865.00
Total dues receivable		$1,085.00
Collections—back dues	$100.00	
Collections—current dues	635.00	
Total collections		735.00
DELINQUENT		$ 350.00
CASH TRANSACTIONS:		
Balance received from former Treasurer	$ 70.45	
Collections	735.00	$ 805.45
Disbursements:		
To A.A.P.G.—bulletin cards	$ 30.00	
Secretarial work (May to December)	80.00	
Application blanks	17.02	
Membership cards	4.55	
Postage	15.00	
Stationery and miscellaneous	28.42	174.99
BALANCE DECEMBER 31, 1934		$ 630.46

Yours very truly,
(Signed) FRAZER AND TORBET
Certified Public Accountants

TULSA, OKLAHOMA
January 10, 1935

FINANCIAL STATEMENT, DIVISION OF PALEONTOLOGY AND MINERALOGY, 1934

To the Society of Economic Paleontologists and Mineralogists,
Gayle Scott, Secretary-Treasurer:

Pursuant to your instructions I have audited the records of the secretary-treasurer of the SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS for the period March 15, 1934, through December 31, 1934, and herewith submit my report.

In my opinion this statement of cash receipts and disbursements is true and correct. All checks were supported by voucher and were properly endorsed. All monies are carried in The Fort Worth National Bank.

Stock of journals on hand is protected by $6,000.00 fire insurance, expiring May 29, 1935.

I found the books and records well kept and the information readily available.

Respectfully submitted,
(Signed) L. A. DUNAGAN

BOX 86, FOREST PARK STATION
FORT WORTH, TEXAS
January 30, 1935

STATEMENT OF CASH RECEIPTS AND DISBURSEMENTS SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS FOR THE PERIOD MARCH 15, 1934, THROUGH DECEMBER 31, 1934

RECEIPTS

Balance on hand March 15, 1934		$3,667.87
Membership dues	$ 413.40	
Donations toward publication A.A.P.G.	354.60	
Donations National Academy of Science	750.00	
Subscriptions	1,702.87	
Advertising	189.04	
Plates and Separates	30.60	
Interest earned by Savings Account	61.68	
National Research Council	150.00	
TOTAL RECEIPTS, MARCH 15, 1934, THROUGH DECEMBER, 31, 1934		3,652.19
TOTAL ASSETS		$7,320.06

DISBURSEMENTS

Secretarial and clerical	$ 475.00	
Telephone and telegraph	4.00	
Postage and deposits on permits	146.00	
Tax on checks and collection expense	2.07	
Printing and stationery	47.45	
Reprints	6.06	
Freight on covers	2.00	
Insurance on stock of journals	33.60	
Gayle Scott to G.S.A. trip (part)	50.00	
Miscellaneous	21.84	
Loss by theft (subscriptions)	10.00	
Audit	25.00	
Binding S-P Vol. 3	2.50	
Returned items:		
Texas State Warrant (not yet payable)	6.00	
Printing:		
Journal of Paleontology		
March	357.51	
June	1,347.17	
September	784.05	
December	148.00	
Journal of Sedimentary Petrology		
April	268.95	
August	235.62	
		$3,972.82
Cash on hand January 1, 1935		$3,347.24

STATEMENT OF ASSETS

SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS, JANUARY 1, 1935

ASSETS

BANK BALANCE:		
Savings Account	$2,681.96	
Checking Account	712.78	
		$ 3,394.74
STOCK OF JOURNALS:		
Journal of Paleontology:		
Volume 2 (38 copies)	228.00	
" 3 (66 copies)	396.00	
" 4 (294 copies)	1,764.00	
" 5 (347 copies)	2,082.00	
" 6 (399 copies)	2,394.00	
" 7 (429 copies)	2,574.00	
" 8 (480 copies)	2,880.00	
		12,318.00
Journal of Sedimentary Petrology:		
Volume 1 (231 copies)	$ 693.00	
" 2 (286 copies)	858.00	
" 3 (396 copies)	1,188.00	
" 4 (371 copies)	1,113.00	
		3,852.00
BILLS COLLECTIBLE:		
Membership dues	108.00	
Sales of journals	149.60	
(23) Journal of Sedimentary Petrology subs.	69.00	
(15) Journal of Sedimentary Petrology dues	30.00	
Advertising	179.37	
Due for back issues of Journals	73.40	
Plates in separates ordered by authors due	51.30	
		660.67
TOTAL		$20,225.41

RECONCILIATION OF BALANCES

Balance Savings Account		$2,681.96
Balance Checking Account	$276.65	
Balance on hand undeposited checks	436.13	712.78
		$3,394.74
Less outstanding checks		47.50
Cash on hand January 1, 1935		$3,347.24

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
MEMBERSHIP LIST

MARCH 1, 1935

HONORARY MEMBERS

The executive committee may from time to time elect as honorary members persons who have contributed distinguished service to the cause of petroleum geology. Honorary members shall not be required to pay dues.—*Sec. 6, Article III, of the Constitution.*

LIFE MEMBERS

The executive committee may grant life membership to members who have paid their dues and are otherwise qualified.—*Sec. 2, Article III, of the Constitution.*

On the payment of three hundred dollars ($300.00) any member in good standing shall be declared a life member and thereafter shall not be required to pay annual dues.—*Sec. 2, Article I, of the By-Laws.*

MEMBERS

Any person engaged in the work of petroleum geology or in research pertaining to petroleum geology or technology is eligible to active membership, provided he is a graduate of an institution of collegiate standing, in which institution he has done his major work in geology, or in sciences fundamental to petroleum geology, and in addition has had the equivalent of three years' experience in petroleum geology or in the application of these other sciences to petroleum geology or to research in petroleum geology or technology; and provided further that in the case of an applicant for membership who has not had the required collegiate or university training, but whose standing in the profession is well recognized, he shall be admitted to membership when his appli ation shall have been favorably and unanimously acted upon by the executive committee, and provided further that these requirements shall not be construed to exclude teachers and research workers in recognized institutions whose work is of such character as in the opinion of the executive committee shall qualify them for membership.

Active members alone shall be known as members.—*Sec. 1, Article III, of the Constitution.*

ASSOCIATES

Any person having completed as much as thirty hours of geology (an hour shall here be interpreted as meaning as much as sixteen recitation or lecture periods of one hour each, or the equivalent in laboratory) in a reputable institution of collegiate or university standing, or who has done field work equivalent to this, is eligible to associate membership, provided at the time of his application for membership he shall be engaged in geological studies in an institution of collegiate or university standing, or shall be engaged in petroleum geology; and any person who is a graduate of an institution of collegiate standing, in which he has done his major work in sciences fundamental to petroleum geology or petroleum technology, and who has had the equivalent of one year's experience in the application of his science to the study of petroleum geology, shall be eligible to associate membership, provided at the time of his application for mem bership he shall be engaged in investigations in the broader subject of petroleum geology and technology.

Associate members shall be known as associates.

Associates shall enjoy all the privileges of membership in the Association, save that they shall not hold office; sign applications for membership, or vote; neither shall they have the privilege of advertising their affiliation with the Association in professional cards or professional reports or otherwise.—*Sec. 3 Article III, of the Constitution.*

HONORARY MEMBERS

(**Deceased)

Campbell, Marius R., 3100 Connecticut Ave., Washington, D.C.
Decker, Charles E., 508 Chatauqua Ave., Norman, Okla.
**Dumble, E. T.
Goodrich, Harold B., 1628 S. Cincinnati, Tulsa, Okla.
Hill, Robert T., c/o Dallas News, Dallas, Tex.
Orcutt, W. W., Union Oil Company Bldg., Los Angeles, Calif.
**Salisbury, R. D.
Schuchert, Charles, Yale University, New Haven, Conn.
Smith, George Otis, Box 308, Skowhegan, Me.
Taff, Joseph A., Associated Oil Co., 79 New Montgomery St., San Francisco, Calif.
**Udden, Johan August
**von Höfer, Hans Hofrat
**White, David
**White, I. C.

COMPLETE LIST OF MEMBERS, ASSOCIATES, HONORARY MEMBERS, AND LIFE MEMBERS

Honorary	8
Life	2
Members	1,602
Associates	375
Total	1,987

EXPLANATION OF SYMBOLS

*Honorary member. †Life member. ‖Associate. Members are not marked. The year refers to the date of election to the Association, not necessarily to class of membership.

‖Abbott, John L., 1209 Fort Worth Natl. Bank Bldg., Forth Worth, Tex. '27
Absher, William F., Geological Dept., Empire Gas & Fuel Co., Bartlesville, Okla. '20
Ackers, A. L., Stanolind Oil & Gas Co., Box 758, Midland, Tex. '25
Adams, Frank C., Gem Oil Co., 1506 Esperson Bldg., Houston, Tex. '27
Adams, John Emery, Drawer R, Midland, Tex. '29
Adams, W. C., Deep Rock Oil Corp., Atlas Life Bldg., Tulsa, Okla. '24
Addison, Carl C., 3032 N. Twenty-First St., Kansas City, Kan. '30
‖Adkisson, Albert, 1816 W. T. Waggoner Bldg., Fort Worth, Tex. '34
Adler, Joseph L., 1517 Branard St., Houston, Tex. '30
Aguerrevere, Pedro I., Sur 3, No. 94, Caracas, Venezuela, S. A. '24
Aguerrevere, Santiago E., Sur 3, No. 94, Caracas, Venezuela, S. A. '24
Aimer, James D., Box 375, Nacogdoches, Tex. '26
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AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

ROY L. LAY, geologist with The Texas Company, has been transferred from Houston, Texas, to Los Angeles, California.

FRED Q. CASLER and ROBERT H. DOTT have organized the Aero Exploration Company, located at 904 Atlas Building, Tulsa, Oklahoma.

FRANK CARNEY, of the geological faculty at Baylor University, Texas, died on December 13 at the age of 66 years.

An International Congress of Mines, Metallurgy, and Economic Geology will be held in Paris, October, 1935. The officers of the section on economic geology are: president, M. CAYEUX; secretary, F. BLONDEL. Details may be secured from the secretary, 13 rue de Bourgogne, Paris, VII.

H. C. ARNOLD has resigned from the geological staff of the Barnsdall Oil Company to join the British American Oil Producing Company, Tulsa, Oklahoma.

C. L. MOHR, of the geological department of the Indian Territory Illuminating Oil Co., has been transferred from San Antonio to Midland, Texas.

S. E. SLIPPER, chief geologist of the Canadian Western Natural Gas, Light, Heat and Power Company, Calgary, Alberta, recently presented a paper "The Development of the Turner Valley Oil Fields," before the Engineering Institute of Canada, Lethbridge branch.

COLLIER COBB, professor of geology at the University of North Carolina, died on November 28, 1934, at the age of 72 years.

W. C. FRITZ is with the Skelly Oil Company at Midland, Texas.

R. D. JONES is employed by the Ardie Oil and Gas Company, 812 N. E. Sixteenth Street, Oklahoma City, Oklahoma.

PAUL D. TORREY, of the Sloan and Zook Company, Bradford, Pennsylvania, has been in the Gulf Coast and Mid-Continent regions for several months.

DAVID WHITE, principal geologist of the United States Geological Survey, connected with the Survey for 49 years, honorary member of The American Association of Petroleum Geologists, died at Washington, D. C., February 7, 1935, at the age of 72 years.

The Rocky Mountain Association of Petroleum Geologists, Denver, Colorado, met at the University of Colorado, February 4. A symposium on "What Colorado Needs in the Way of Geologic Work" was presented by by George, Winchester, Worcester, and Toepelman.